FLOWER VISITING FLIES (INSECTA: DIPTERA) COMMUNITIES IN CUCURBIT PRODUCTION SYSTEMS IN MOROGORO REGION, EASTERN CENTRAL TANZANIA

SIJA AMOS KABOTA

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN CROP SCIENCE OF SOKOINE UNIVERSITY OF AGRICULTURE. MOROGORO, TANZANIA.

2021

EXTENDED ASTRACT

Flower visiting flies are one of the most important beneficial groups of Diptera because of their profound pollination services to more than 19% of flowering plants. Many beneficial insects such as bees which pollinate more than 51% of the flowering plants are serious declining in the ecosystems. The production of many insect-dependent crops are at high risk. Previous studies indicated that some families of flower visiting flies contain efficient pollinator species (Larson *et al.,* 2001). These species could be of great importance in maintaining ecosystem service and safeguarding the production of many flowering plants including cucurbit crops. However, knowledge on community structures and visitation rates of flower visiting flies associated with cultivated cucurbit crops is limited in Tanzania. A thoroughly understanding of community structures and visitation rates of flower visiting flies is a prerequisite if their potential is to be realized in agriculture. Therefore, this study assessed the community structures and flower visit activities of flower visiting flies associated with cucurbitaceous production systems in the Morogoro region.

Experiments were laid out in a full factorial design. Factors were seasons, agroecological zones, flowering weeks and fly species. Sampling of flies visiting cucurbit flowers was carried out using yellow pan traps and a hand net supplemented with observational counts, in ten established cucurbit fields across the mountainous and plateau zone of the Morogoro region from March to July 2020.

A total of 7 606 specimens belonged to 22 genera and 8 families of flower vising flies were collected during the study period. Of which 77.58% of all specimens were collected from mountainous zone and the remaining 22.42% were from the plateau zone. Among the hoverfly species examined, *Eristalinus megacephalus* Rossi, *Mesembrius caffer* Loew and *Toxomerus floralis* Macquart showed significant variation in visitation rate, foraging time and abundance across the two agroecological zones, season and sampling weeks (P<0.05). The abundance of these species fluctuated significantly across the two agroecological zones between the wet and dry season (P<0.05). On other hand, both Shannon, Simpson and Margalef indexes placed the mountainous zone as the most abundant and species rich zone in term of number of species. Species abundance distribution models indicated hierarchically arrangement of flower visiting fly's communities within cucurbit crops. All fields were highly similar as most of the species were shared between fields within each zone.

Agroecosystems at different altitudes have different community structures and species within these ecosystems differ in floral visitation rates. The obtained data so far seem to suggest that hoverfly species should be considered as an important pollinators of cucurbit crops. We recommend that a detailed study of pollination efficiency, floral preference and diurnal activities of hoverfly species should therefore be considered a high priority.

Key words; Diversity, Hover fly, Spatial abundance, temporal abundance, Flower visiting flies, Cucurbit crops, Visitation rate.

DECLARATION

I, Sija Amos Kabota, do hereby declare to the Senate of Sokoine University of Agriculture that this thesis is my own original work, which is done within the period of registration, and that it has never been submitted nor is it being concurrently submitted in any other institution.

Sija Amos Kabota — Date

(M.Sc. Candidate)

The above declaration is confirmed by:

Prof. Maulid W. Mwatawala — Date

(Supervisor)

COPYRIGHT

ACKNOWLEDGEMENTS

First and foremost, I would like to thank God almighty for giving me the strength, knowledge, ability and opportunity to undertake this research work and to persevere and complete it satisfactory. Without his blessings, this achievement would not have been possible. I am thankful to my employer, the Ministry of Agriculture (MOA) of United Republic of Tanzania for giving me the opportunity to further my education. I am grateful to MOA and the Royal Museum for Central Africa (RMCA) through the Agroecological Methodology for Vegetable crops (AGROVEG) Project for the financing this study.

I am glad to express sincere thanks to my supervisor Prof. Maulid Mwatawala of Department of Crop science and Horticulture (DCSH), College of Agriculture at Sokoine University of Agriculture (SUA) for his intellectual and moral support to me throughout this research work. His knowledge pool and guidance was always available to guide me through data collection, correction and regular monitoring of the writing process of my dissertation.

Many thanks to Dr Marc De Meyer, Dr Massiliano Virgilio and Dr Kurt Jordaens (RMCA) for confirmation of syrphid identifications, Dr. Ashley H Kirk- Spriggs (Natural History Museum, London, UK) for making available his Manual of Afrotropical Diptera Volume 1 and 2. Many thanks also go to the AGROVEG-Project leaders for organizing the training on Systematic and Taxonomic identification of pollinating flies.

I also wish to express my sincerely appreciation to Dr. Abdul Kudra and Dr. Ramadhan Majubwa as well as the entire academic community and supporting staff from the DCSH at SUA for their support and contribution in my study.

I sincerely express my thanks to my beloved wife, Fatma Salum Mussa, my son and daughter (Nurdin and Khadija) for their patience and difficulties they came across during my absence.

Lastly, I am eager to express my thanks to my fellow students Petronila P. Tarimo, Patroba M. Bwire, Constantine J. Kimario and Nicholas Mwakinyala for their support and experience sharing during the process of doing my dissertation.

DEDICATION

I dedicate this work to my beloved Parents (Tatu Khamis and Amos Kabota) for laying the foundation of my education profile.

LIST OF PAPER CHAPTERS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABREVIATIONS AND SYMBOLS

^0C	Degree Centigrade
ABE	Abundance-based Estimator
ACE	Abundance-based Coverage Estimator
AIK	Akaike Information Criterion
ANOVA	Analysis of Variance
CM	Crop Museum
HT	Horticulture Unit
KF	Kifulu
MF	Mafiga
MG	Mgola
MK	Mkumbulu
MS	Morning Side
MZ	Mazimbu
RU	Ruvuma
SAC	Species Accumulative Curves
SAD	Species Abundance Distribution
SE	Standard error
SUA	Sokoine University of Agriculture
SUGECO	Sokoine University Graduate Entrepreneurs Cooperative
TMA	Tanzania Meteorological Authority
URT	United Republic of Tanzania

CHAPTER ONE

1.0 General Introduction

1.1 Background

Cultivation of fruit vegetables is one among major economic activities that employ majority of small scale farmers in Tanzania (Sawe *et al.,* 2020a). Fruit vegetables particularly watermelon, cucumber, tomato, squash and pepper are among major crops cultivated for foods and income generation by many farmers in rural and urban areas (Khalid *et al.,* 2011). Fruit vegetables are source of dietary fibers, vitamins, minerals and phytochemicals that have a wide range of health benefits in the body (Brookie *et al.,* 2018; Wallace *et al.,* 2019).

Globally, the demand and consumption rate of fruit vegetables is increasing (Peters *et al.,* 2016; Sawe *et al.,* 2020b). There is great potential for growth of fruit vegetable markets due to increasing awareness of health and nutritional benefits related to the consumption of fruit vegetables (Sthapit *et al.,* 2012). However, the production of these fruit vegetables in Tanzania is greatly hampered by many factors including pest infestation, diseases and insufficient pollination services (Peters *et al.,* 2016; Sawe *et al.,* 2020a).

Insufficient pollination services in agro-ecosystems is due to decline of animal pollinators, particularly insects (Flores *et al.,* 2019; Thomson, 2019). These pollinators, basically transfer pollens within or between the entomophilous plant species to facilitate the reproduction success and distribution of pollinator-dependent plants (Jauker *et al.,* 2012; Breeze *et al.,* 2019).

The primary insect pollinators belong to the orders Hymenoptera (bees and wasps) and Diptera (true flies) (Ssymank *et al.,* 2008). Although species from the order Hymenoptera are widely recognized as the most important pollinators of agricultural crops, flower visiting flies are the second most important nectarophagous and pollenophagous after bees (Koski *et al.,* 2018; Bashir *et al.*, 2019). However the contribution of these flies to crop productivity in Tanzania remains largely unknown. This is probably due to limited information on abundance, diversity and distribution in agro-ecosystems.

Flower visiting flies are regular flower-visiting insects that mostly hover on flowers of more than 555 plant species including over 100 cultivated crops to obtain foods and mates (Mokam *et al.*, 2014; Latif *et al.*, 2019). More than 19% of flowering plants are pollinated by flies, contributing to 35% of the global food production volume (Aizen *et al.*, 2009; Giannini *et al.*, 2015). About 71 families of flower visiting flies contain flower-visiting flies (Klein *et al.,* 2007; Aizen *et al.*, 2009) and many species of these families have been documented as pollinators ranging from generalist to specialist (Larson *et al.*, 2001; Marshall and Kirk-Spriggs, 2017).

Most species of the families Bombyliidae, Rhiniidae, Syrphidae, Calliphoridae and Muscidae are likely to be the general pollinators (Courtney *et al.,* 2009; Marshall and Kirk-Spriggs 2017). The effectiveness of these flies in offering pollination services varies among species, altitudes, ecologies, host plants as well as seasons (Artins *et al.*, 2001; Klecka *et al.,* 2018).

Studies have shown that pollination effectiveness of flower visiting flies can reach up to 80% in high altitude areas, where their diversity and abundance exceed that of Hymenoptera (Bulganin, 2010; Klecka *et al.,* 2018). Therefore, absence of these flies in such areas would result in more than 90% loss in fruit production (Bashir *et al.,* 2019).

Production deficit due to inadequate pollination service has raised concern all over the world (Biesmeijer *et al.,* 2006; Bulganin, 2010). The food production deficit due to this inadequate pollination service has much been experienced in developing countries compared to elsewhere in the world (Aizen *et al.,* 2009; Garibaldi *et al.,* 2020). Studies indicate that the production deficit in developing countries is estimated to range between 5% to 8% (Delgado-Carrillo *et al.*, 2018; Sawe *et al.,* 2020b). High attention has been on productivity of pollinator-dependent crops including cucurbit crops (Bashir *et al.*, 2019; Sawe *et al.*, 2020a).

Cucurbit crops have imperfect flowers that depend on insect pollinators for setting seeds and fruits (Hodges and Baxendale, 2007; Solange *et al.*, 2008). Absence of pollinators in these crops will result in more than 95% fruit production loss (Klein *et al.,* 2007; Rader *et al.,* 2013). Agriculture intensification, climate change, indiscriminant pesticide use, spread of invasive species and disease as well as availability of key resources are among the major drivers of pollinator decline (Albano *et al.,* 2009; Arthur *et al.,* 2010).

Thefore, the pollinator communities have suffered a serious loss, both in terms of species diversity and species abundance, as in flower visitation rate (Delgado-Carrillo *et al.*, 2018; Genung *et al.,* 2017). Important pollinators such as bees are no longer sufficient to meet the pollination requirements in ecosystems (Delgado-Carrillo *et al.,* 2018; Galbraith *et al.,* 2019), indicating the need to investigate the role of other pollinators to maintain food security. Otherwise, catastrophic consequences of pollinator decline are expected to occur more often in the near future.

1.2 Justification

As a diverse and ubiquitous group of pollinators, Diptera have the potential to contribute significantly to the production of crops, including cucurbit crops (Mokam *et al.,* 2014; Orford *et al.,* 2015; Genung *et al.,* 2017). Previous studies have shown that Diptera are effective pollinators of important crops such as onion, strawberry, pepper, tomato, mango and cocoa (Larson *et al.*, 2001; Orford *et al.*, 2015; Bashir *et al.*, 2019), and therefore, they could be effective pollinators to watermelon, cucumber and squash. However, little is known about their diversity, visitation rate, and spatial and temporal abundance in Tanzania, and this also holds for the Morogoro region. Therefore, more knowledge on pollinating flies would provide pointers for effective pollinator conservation strategies and designing of inventory list. Thus, the present study evaluated the diversity of all flower visiting flies found in cucurbit crops and later focused on visitation rate, spatial and temprol abundance hoverflies foraging cucurbit crops. The more focused towards hoverflies rather than on other families which were apparently more abundant such as Muscidae was due to prior known roles of hoverflies as pollinators, indicators for biodiversity assessment, biocontrol agents for aphids as well as their relatively better known taxonomic identification.

1.3 Objectives

1.3.1 Overall objective

To establish community structure of flower visiting flies associated with Cucurbitaceous production systems for sustainable conservation and management of insect pollinators in the agro-ecosystem.

1.3.2 Specific objectives

i. To assess the diversity and species composition of flower visiting flies associated with cucurbitaceous production systems.

ii. To evaluate visitation rate and species abundance of hoverflies foraging on cucurbit crops.

iii. To determine the spatial and temporal abundance of hoverflies foraging in cucurbitaceous production systems.

References

Aizen, M. A., Garibaldi, L. A., Cunningham, S. A. and Klein, A. M. (2009). How much does agriculture depend on pollinators? Lessons from long-term trends in crop production. *Annals of Botany* 103(9): 1579–1588.

Albano, S., Salvado, E., Borges, P. A. V. and Mexia, A. (2009). Floral visitors their frequency activity rate and Index of Visitation Rate in the strawberry fields of Ribatejo Portugal : Selection of potential pollinators. *Advances in Horticultural Sciences* 23(4): 238–245.

Arthur, A. D., Li, J., Henry, S. and Cunningham, S. A. (2010). Influence of woody vegetation on pollinator densities in oilseed Brassica fields in an Australian temperate landscape. *Basic and Applied Ecology* 11(5): 406–414

Artins, R. O. P. M., Geral, D. D. B. and Federal, U. (2001). Seasonal Abundance and Species Composition of Flower-Visiting Flies. *Neotropical Entomology* 30(3): 351–359.

Bashir, M. A., Saeed, S., Sajjad, A., Khan, K. A., Ghramh, H. A., Shehzad, M. A., Mubarak, H., Mirza, N., Mahpara, S., Rehmani, M. I. A. and Ansari, M. J. (2019). Insect pollinator diversity in four forested ecosystems of southern Punjab, Pakistan. *Saudi Journal of Biological Sciences* 26(7): 1835 – 1842.

Biesmeijer, J. C., Roberts, S. P. M., Reemer, M., Ohlemüller, R., Edwards, M., Peeters, T., Schaffers, A. P., Potts, S. G., Kleukers, R., Thomas, C. D., Settele, J. and Kunin, W. E. (2006). Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. *Science* 313(5785): 351–354.

Breeze, T. D., Boreux, V., Cole, L., Dicks, L., Klein, A., Pufal, G., Balzan, M. V., Bevk, D., Bortolotti, L., Petanidou, T., Mand, M., Pinto, M. A., Scheper, J., Stanisavljević, L., Stavrinides, M. C., Tscheulin, T., Varnava, A. and Kleijn, D. (2019). Linking farmer and beekeeper preferences with ecological knowledge to improve crop pollination. *People and Nature* 1(4): 562–572.

Brookie, K. L., Best, G. I. and Conner, T. S. (2018). Intake of raw fruits and vegetables is associated with better mental health than intake of processed fruits and vegetables. *Frontiers in Psychology* 9(4): 1–14.

Bulganin, M. (2010). Diversity of flower-visiting flies (Insecta: Diptera) in India and their role in pollination. *Records of the Zoological Survey of India* 110(2): 95–107.

Courtney, G. W. and Cranston, P. S. (2015). Phylum arthropoda Order Diptera. In: *Thorp and Covich's Freshwater Invertebrates: Ecology and General Biology*. (Edited by Thorp, J. H. and Rogers, D.C.), Academic Press, London. UK. pp. 1043 – 1058.

Courtney, G. W., Pape, T., Skevington, J. H. and Sinclair, B. J. (2009). *Biodiversity of Diptera.* Blackwell publishing, Canada. 38pp.

Delgado-Carrillo, O., Martén-Rodríguez, S., Ashworth, L., Aguilar, R., Lopezaraiza-Mikel, M. and Quesada, M. (2018). Temporal variation in pollination services to Cucurbita moschata is determined by bee gender and diversity. *Ecosphere* 9(11): 1 – 17.

Flores, L. M. A., Zanette, L. R. S., Boscolo, D. and Araújo, F. S. (2019). Landscape structure effects on bee and wasp assemblages in a semiarid buffer zone. *Landscape Online* 76: 1 – 17.

Galbraith, S. M., Cane, J. H., Moldenke, A. R., and Rivers, J. W. (2019). Salvage logging reduces wild bee diversity, but not abundance, in severely burned mixed-conifer forest. *Forest Ecology and Management* 453(9): 117 – 622.

Garibaldi, L. A., Sáez, A., Aizen, M. A., Fijen, T, and Bartomeus, I. (2020). Crop pollination management needs flower-visitor monitoring and target values. *Journal of Applied Ecology* 57(4): 664 – 670.

Genung, M. A., Fox, J., Williams, N. M., Kremen, C., Ascher, J., Gibbs, J. and Winfree, R. (2017). The relative importance of pollinator abundance and species richness for the temporal variance of pollination services. *Ecology* 98(7): 1807–1816.

Giannini, T. C., Boff, S., Cordeiro, G. D., Cartolano, E. A., Veiga, A. K., Imperatriz-Fonseca, V. L. and Saraiva, A. M. (2015). Crop pollinators in Brazil: a review of reported interactions. *Apidologie* 46(2): 209 – 223.

Hodges, L. and Baxendale, F. (2007). *Bee Pollination of Cucurbit Crops*. N. Institute of Agriculture and Natural Resources, Lincoln. 218pp.

Jauker, F., Bondarenko, B., Becker, H. C. and Steffan-Dewenter, I. (2012). Pollination efficiency of wild bees and hoverflies provided to oilseed rape. *Agricultural and Forest Entomology* 14(1): 81 – 87.

Khalid, U., Nosheen, F., Asif Raza, M., Ishaque, M., Ahmad, M., Ahmad, S. R. and Rubab, F. (2011). A comparative study about the daily intake of fruits and vegetables among female students of two universities of Faisalabad. *Pakistan Journal of Nutrition* 10(7): 684 – 689.

Klecka, J., Hadrava, J., Biella, P. and Akter, A. (2018). Flower visitation by hoverflies (Diptera: Syrphidae) in a temperate plant-pollinator network. *Peer Journal* 2018: 1 – 12.

Klein, A. M., Vaissière, B. E., Cane, J. H., Steffan-Dewenter, I., Cunningham, S. A., Kremen, C. and Tscharntke, T. (2007). Importance of pollinators in changing landscapes for world crops. Proceedings of the Royal Society B*: Biological Sciences* 274(1608): 303 – 313.

Koski, M. H., Ison, J. L., Padilla, A., Pham, A. Q. and Galloway, L. F. (2018). *Linking Pollinator Efficiency to Patterns of Pollen Limitation: Small Bees Exploit the Plant-Pollinator Mutualism*. Royal Society Publishing, USA. 10pp.

Larson, B. M. H., Kevan, P. G. and Inouye, D. W. (2001). Flies and flowers: Taxonomic diversity of anthophiles and pollinators. *Canadian Entomologist* 133(4): 439 –465.

Latif, A., Malik, S. A., Saeed, S., Zaka, S. M., Sarwar, Z. M., Ali, M., Azhar, M. F., Javaid, M., Ishtiaq, M., Naeem-Ullah, U., Naoreen, M., Khan, K. A., Ghramh, H. A. and Shahzad, M. A. (2019). Pollination biology of Albizia lebbeck (L.) Benth. (Fabaceae: Mimosoideae) with reference to insect floral visitors. *Saudi Journal of Biological Sciences* 26(7): 1548 – 1552.

Marshall S. A. and Kirk-Spriggs, A. H. (2017). Natural history of diptera. In: *Manual of Afrotropical Diptera, Introductory Chapters and Keys to Diptera Families*. (Edited by Kirk-Spriggs, A. H. and Sinclair, B. J.), South Africa National Biodiversity Institute, Pretoria, South Africa. pp. 135 – 152.

Mokam, D. G., Djiéto-Lordon, C., Bilong, C. F. B. and Brunet, J. (2014). Patterns of species richness and diversity of insects associated with cucurbit fruits in the southern part of Cameroon. *Journal of Insect Science* 14:1 – 9.

Orford, K. A., Vaughan, I. P. and Memmott, J. (2015). The forgotten flies: the importance of non-syrphid Diptera as pollinators. Proceedings of the Royal Society: *Biological Sciences* 282(1805): 2014 – 2934.

Peters, M. K., Ferger, S. W., Classen, A., Peters, M. K., Ferger, S. W., Helbig-bonitz, M., Schmack, J. M., Maassen, G. and Schleuning, M. (2016). *Complementary Ecosystem Services Provided by Pest Predators and Pollinators Increase Quantity and Quality of Coffee Yields Complementary Ecosystem Services Provided by Pest Predators and Pollinators Increase Quantity and Quality of Coffee Yields*. Royal Society Publishing, USA. 8pp.

Rader, R., Reilly, J., Bartomeus, I. and Winfree, R. (2013). Native bees buffer the negative impact of climate warming on honey bee pollination of watermelon crops. *Global Change Biology* 19(10): 3103 – 3110.

Sawe, T., Eldegard, K., Totland, Ø., Macrice, S. and Nielsen, A. (2020). Enhancing pollination is more effective than increased conventional agriculture inputs for improving watermelon yields. *Ecology and Evolution* 10(12): 5343 – 5353.

Sawe, T., Nielsen, A., Totland, Ø., Macrice, S. and Eldegard, K. (2020). Inadequate pollination services limit watermelon yields in northern Tanzania. *Basic and Applied Ecology* 44: 35 – 45.

Solange, A. B. S., Ana, C. R. and Luci, R. B. (2008). Pollination of Cucumber Cucumis sativus L (Cucurbitales: Cucurbitaceae), by the Stingless Bees Scaptotrigona aff. depili Moure and Nannotrigona testaceicornis Lepeletier (Hymenoptera: Meliponini) in Greenhouses. *Neotropical Entomology* 37(5): 506 – 512.

Ssymank, A., Kearns, C. A. and Pape, T. (2007). Pollinating Flies (Diptera): A major contribution to plant diversity and agricultural production. *Biodiversity* 9(2): 86 – 89.

Sthapit, B., Rao, V. R. and Sthapit, S. (2012). *Tropical Fruit Tree Species and Climate Change*. Biodiversity International. New Delhi.

Thomson, D. M. (2019). Effects of long-term variation in pollinator abundance and diversity on reproduction of a generalist plant. *Journal of Ecology* 107(1): 491–502.

Wallace, T. C., Bailey, R. L., Blumberg, J. B., Burton-Freeman, B., Chen, C. O., Crowe-White, K. M., Drewnowski, A., Hooshmand, S., Johnson, E., Lewis, R., Murray, R., Shapses, S. A. and Wang, D. D. (2019). Fruits, vegetables, and health: A comprehensive narrative, umbrella review of the science and recommendations for enhanced public policy to improve intake. *Critical Reviews in Food Science and Nutrition* 1: 1 – 38.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 General overview of order Diptera

The order Diptera represent a holometabolous group of insects with, in the majority of species, a single pair of functional wings in its adult members (Fusari *et al.,* 2018). Its adult members are recognized by the reduced second pair of metathoracic wings, called halteres (Bertone, 2019; Chiri, 2017). The halteres are used for stabilizing flight (Fusari *et al.,* 2018). The order Diptera is one of the three largest and diverse groups of animals, accounting for 14% of animal diversity on earth (Ssymank *et al.,* 2007). A recent review by Marshall and Kirk-Spriggs (2017) indicated that, there are over 160 042 species of Diptera, in approximately 10 000 genera known worldwide, of which 20 350 are known from the Afrotropical Region. In their prediction Marshall and Kirk-Spriggs (2017) further pointed out that there are more than 30 000 species from the order Diptera yet to be described in the Afrotropical region. This implies that only one third of the dipteran species in the Afrotropical Region have been described, while a vast number of species has remained undocumented (Marshall and Kirk-Spriggs, 2017).

Diptera flies are believed to be among the ancient flies on the earth, with their fossil records dating back to 250 million years ago (Courtney e*t al.,* 2009). Previous studies also indicated that Diptera were the first pollinators of flowering plants on Earth (Merritt *et al.,* 2009) and that Diptera played a significant role in the radiation of angiosperms (Ssymank *et al.,* 2008).

2.2 Overview on classification of Diptera flies

Based on antennae types and body shapes, diptera flies were first traditionally, classified into two suborders, Nematocera (Thread-horned flies) and Brachycera (short-horned flies) (Fusari *et al.*, 2018). Later, three suborders were recognized, Nematocera (crane flies, mosquitoes, midges), Brachycera (soldier flies, horse flies, robber flies, bee flies), and Cyclorhapha (house flies, blow flies, flesh flies) (Chiri, 2017). The distinction between these suborders was based on antennal shape, the number of antennal segments and maxillary palp morphology, as well as the morphology of the larvae and puparia (Fusari *et al.*, 2018; Hine, 1904). For instance, the nematoceran flies are easily recognized by their long and multi-segmented antennae (usually more than eight segments)(Chiri, 2017; Hine, 1904). The adults in this suborder are generally delicate, long-legged flies such as Tipulidae and Culicidae (Hine, 1904). The sub-order contains stouter-bodied flies such as Simuliidae and Ceratopogonidae (Bertone, 2019; Hine, 1904).

On other hand, adult Brachycera flies contain short, three-segmented antennae with either style or arista. All Brachycera flies have two or fewer segments in the maxillary palp (Hine, 1904; Marshall and Kirk-Spriggs, 2017). Larvae from this suborder possess a hemicephalic/acephalic capsule and mouthparts with a slender rod largely retracted into the thorax (Ruíz, 2015). This indicates that Brachycera flies are more evolutionary developed as compared to the Nemotocera (Chiri, 2017). However, the suborder Cyclorhapha (circular-seamed flies) is generally a developmental deviation from the suborder Brachycera (de Oliveira *et al.*, 2017). Some adults of Brachycera underwent major adaptations which enabled them to escape the puparium stage (de Oliveira *et al.*, 2017; Hine, 1904). Most Cyclorhapha species share multiple attributes such as the 360-degree rotation of the male terminalia (de Oliveira *et al.*, 2017).

Current review on dipteran flies classification based on morphology and limited molecular analysis indicates that the order Diptera can be divided into five major suborders (infraorders) namely; Bibionomorpha, Brachycera, Culicomorpha, Psychodomorpha and Tipulomorpha (Wiegmann *et al.,* 2011).

2.3 Feeding habits among Diptera flies

Diptera flies are among diverse insect groups in term of feeding habits. Their feeding habits differ among species and growth stage, and have profound impacts on ecosystems (Skevington and Dang, 2002). Nearly half of the fly's species larvae feed on dead animal and plant materials which in turn contribute substantial to the decomposition of organic materials (Thiemann *et al.,* 2012). For instance, many larval Diptera feed in leaf-litter, rotting wood, rotting fruit or other organic matter such as slime, flowing sap, and rotting cacti, carrion, dung, detritus in mammal bird and wasp nests (Nartshuk, 2014). Other flies (both larvae and adults) are predators that acquire energy by killing and consuming prey organisms (Skevington and Dang, 2002). They are considered as natural enemies of a wide variety of organisms. Of the 128 currently recognized families of Diptera, 42 are known to include predacious members (Sarwar, 2020). In addition, parasitic flies live in intimate association with a host from which they obtain food and other benefits at the host's expense (Amancio *et al.,* 2019). They cause some degree of overt damage but usually do not kill their host (Xue and Barnard, 2008). They feed on mammals and other insects. For instance larvae of all Oestridae and adults of Culicidae and Calliphoridae are parasites of mammals while larvae of Tachinidae are parasites of other insects (Rotheray and Lyszkowski, 2015). Moreover, other group of flies are parasitoids that feed on living host tissues in an orderly sequence until the host is killed, with death to the host occurring only after larval development of the parasitoid is complete (Sarwar, 2020). About 20% of the total Diptera species are parasitoids (Skevington and Dang, 2002). Other non Diptera

(Hymenoptera), Wasps and their relatives account for 78% of the parasitoid species (Sarwar, 2020). Flies are also serving as pollinators and contribute to the propagation and dispersion of flowering plants (Amancio *et al.,* 2019). Flowers are important sources of food. Adult flies require energy for flight in dispersing, finding mates, mating, and searching out sites for oviposition (Larson *et al.,* 2001). For instance, long-tongued flies, such as Nemestrinidae and Tabanidae are among important pollinators of deep tubed flowers which are source of nectar (Goldblatt and Manning 2000). A wide variety of flies also feed on pollens as their important source energy. These include notorious flower flies (Syrphidae).

2.4 Diversity and distribution of Diptera flies

Diptera are among the four most diverse orders of insects with more than 160 042 species described worldwide in approximate 188 families (Marshall and Kirk-Spriggs, 2017; Courtney and Cranston, 2015; Merritt *et al.,* 2009). The group is ubiquitous and cosmopolitan, having successfully colonized nearly every habitats on the earth ranging from aquatic to terrestrial environment (Courtney *et al.*, 2009; Larson *et al.,* 2001).

The dipteran flies are widely distributed in all continents, extending from Africa to Antarctica (Bashir *et al.,* 2019; Marshall and Kirk-Spriggs, 2017). They exist in considerable high numbers in all regions of the world including the Afrotropical region (Bertone, 2019; Fusari *et al.*, 2018), where approximately 108 families of Diptera are known to occur, accounting to 57% of all known Diptera families in the global (Marshall and Kirk-Spriggs, 2017).

There are at least ten best represented families with nearly 500 species occurring in Afrotropical region, Tanzania included (Marshall and Kirk-Spriggs, 2017). These include well known families such as Asilidae Bombyliidae, Chironomidae, Cullicidae, Dolichopodidae, Limoniidae and Tipulidae, Muscidae, Syrphidae, Tabanidae, Tachinidae and Tephritidae (Marshall and Kirk-Spriggs, 2017; Kirk-Spriggs and Sinclair, 2017).

As one among major successful group of insects on the world with more than 14 126 species involved in the process of pollination (Bulganin, 2010), dipteran flies are also considered to be the most diverse and well distributed group in the Afrotropical Region particularly in Tanzania (Bulganin, 2010). Although the present reviews on dipteran flies present figures on the diversity and distribution of these flies in a regional context (Marshall and Kirk-Spriggs, 2017; Kirk-Spriggs and Sinclair, 2017), studies indicating those parameters at small scale level within a country in the Afrotropical Region are very limited.

2.5 Agricultural significance of Diptera flies

Approximately, one third of Nematocera families forage on flowers in tropical and subtropical habitats to obtain nectar and pollen (Courtney and Cranston, 2015; Kirk-Spriggs and Sinclair, 2017). These include obligate nectar-feeders such as Culicidae and Simuliidae which mainly visit short tubed or hidden flowers with readily accessible nectar (Courtney *et al.,* 2009; Larson *et al.,* 2001; Marshall and Kirk-Spriggs, 2017).

In contrast, Brachycera contains a wider variety of regular flower visitors and nectar-feeders of long tubed flowers (Courtney *et al.,* 2017). Studies have also reported that both long and short-tongued form Brachycera species are nectarivorous (Marshall and Kirk-Spriggs 2017; Fusari *et al.,* 2018). Although many ecosystems in Tanzania seems to harbor considerable numbers and diversity of flies (Sawe *et al*., 2020b; Sawe *et al.,* 2020a), studies focusing on the diversity and visitation rate, as well as on the spatial and temporal distribution, of pollinating flies are scarce.

2.6 Effects of agricultural practices on flower visiting flies

Agriculture poses many dangers to important insects as such as flower visiting flies in farm lands (Didham et al., 1996). Agricultural practices that involve changes in land use, loss and fragmentation of habitat, introduction of exotic organisms and discriminate use pesticide adversely affect the insect abundance and species diversity of important flower visitors in the farmlands (Dirzo and Raven 2003;Nicholls and Altieri, 2012). Some of the most used modern agriculture system such as monoculture characterized by dominated single crop that produces uniform flowers with similar sizes, shapes, and colors interrupts the mutualism interaction of insects and plants (Willmer, 2011). Likewise, removal of hedges, weed patches, field margins, and uncultivated land that formerly provided floral resources, nesting sites and habitants impact directly or indirectly the flower vising flies abundance and species richness in agroecosystems (Richards 2001; Kremen et al. 2002). Many features associated with modern agriculture such as monoculture make farmlands poor habitat for flower visiting flies. Intensification of monoculture has led to a more homogeneous landscape characterized by large weed-free fields and fewer non cultivated habitats (Siregar *et al.,* 2016), and it has been linked to the reduction in insect abundance and species richness in agricultural landscapes (Kevan 1999). On other hand farming practices that focus on maintaining nesting habitats and increasing of floral resources within farmland tend to increases the abundance and diversity of important insects such as flower visiting flies in agroecosystem (Ramos *et al.,* 2018).

References

Amancio, G., Hernández-Ortiz, V., Aguirre-Jaimes, A., Guevara, R., and Quesada, M. (2019). Feeding Specialization of Flies (Diptera:Richardiidae) in Aroid Infructescences (Araceae) of the Neotropics. *Journal of Insect Science* 19(3): 1-7.

Bashir, M. A., Saeed, S., Sajjad, A., Khan, K. A., Ghramh, H. A., Shehzad, M. A., Mubarak, H., Mirza, N., Mahpara, S., Rehmani, M. I. A. and Ansari, M. J. (2019). Insect pollinator diversity in four forested ecosystems of southern Punjab, Pakistan. *Saudi Journal of Biological Sciences* 26(7): 1835–1842.

Bulganin, M. (2010). Diversity of flower-visiting flies (Insecta: Diptera) in India and their role in pollination. *Records of the Zoological Survey of India* 110(2): 95 – 107.

Chiri, A. (2017). Common Flies (Order Diptera) in the Wichita Mountains and Surrounding Areas. *National Wildlife Refuge System* 3: 1 – 9.

Courtney, G. W., Pape, T., Skevington, J. H. and Sinclair, B. J. (2009). *Biodiversity of Diptera.* Blackwell publishing, Canada. 38pp.

de Oliveira, J. L., Sobrinho-Junior, I. S., Chahad-Ehlers, S. and de Brito, R. A. (2017). Evolutionary coincidence of adaptive changes in exuperantia and the emergence of bicoid in Cyclorrhapha (Diptera). *Development Genes and Evolution* 227(5): 355 – 365.

Didham R.K.,Ghazoul J., Stork N.E and Davis A.J.(1996). Insects in fragmented forest: a functional approach. *Trends in Ecology and Evolution* 11(6):255-260.

Dirzo R.T and Raven P.H. (2003). Global state of biodiversity and loss. *Annual Review of Environment Resources* 28(1):137-167

Fusari, L. M., Dantas, G. P. S. and Pinho, L. C. (2018). Order Diptera. Keys to Neotropical Hexapoda. In Thorp and Covich’s Freshwater Invertebrates. *Science Direct* 3: 607 – 623.

Goldblatt, P., and Manning, J. C. (2000). The long-proboscid fly pollination system in southern Africa. *Annals of the Missouri Botanical Garden* 87 (2):146-170.

Hine, J. S. (1904). The diptera of British Columbia. *The Canadian Entomologist* 36(4): 85–92.

Kevan P.G. (1999). Pollinators as bio-indicators of the state of the environment: species, activity and diversity. *Agriculture, Ecosystem and Environment* 74 (1-3): 373–393

Kirk-Spriggs, A. H. and Sinclair, B. J. (2017). *Manual of Afrotropical Diptera Volume 2. Nematocerous Diptera and lower Brachycera*. South Africa National Biodiversity Institute, Pretoria, South Africa. 956pp.

Kremen C., Williams N.M., Thorp R.W. (2002) Crop pollination from native bees at risk from agricultural intensification. *Proceedings of the National Academy of Sciences of the United States of America*. 99:16812–16816

Larson, B. M. H., Kevan, P. G. and Inouye, D. W. (2001). Flies and flowers: Taxonomic diversity of anthophiles and pollinators. *Canadian Entomologist* 133(4): 439 – 465.

Marshall S. A. and Kirk-Spriggs, A. H. (2017). Natural history of diptera. In: *Manual of Afrotropical Diptera, Introductory Chapters and Keys to Diptera Families*. (Edited by Kirk-Spriggs, A. H. and Sinclair, B. J.), South Africa National Biodiversity Institute, Pretoria, South Africa. pp. 135 – 152.

Merritt, R. W., Courtney, G. W. and Keiper, J. B. (2009). Diptera: (Flies, Mosquitoes, Midges, Gnats). *Encyclopedia of Insects* 1: 284 – 297.

Nartshuk, E. P. (2014). Grass-fly larvae (Diptera, Chloropidae). Diversity, habitats, and feeding specializations. *Entomological Review* 94(4): 514–525.

Nicholls, C. I., and Altieri, M. A. (2012). Plant biodiversity enhances bees and other insect pollinators in agroecosystems. A review. *Agronomy for Sustainable Development* 33(2): 257–274.

Ramos, D. L., Bustamante, M. M., Silva, F. D., and Carvalheiro, L. G. (2018). Crop fertilization affects pollination service provision–common bean as a case study. *PloS one* 13(11):1-16.

Richards, A. J. (2001). Does low biodiversity resulting from modern agricultural practice affect crop pollination and yield?. *Annals of botany* 88(2): 165-172.

Rotheray, G., and Lyszkowski, R. (2015). Diverse mechanisms of feeding and movement in Cyclorrhaphan larvae (Diptera). *Journal of Natural History* 49(35-36): 2139–2211.

Sawe, T., Eldegard, K., Totland, Ø., Macrice, S. and Nielsen, A. (2020). Enhancing pollination is more effective than increased conventional agriculture inputs for improving watermelon yields. *Ecology and Evolution* 10(12): 5343 – 5353.

Sawe, T., Nielsen, A., Totland, Ø., Macrice, S. and Eldegard, K. (2020). Inadequate pollination services limit watermelon yields in northern Tanzania. *Basic and Applied Ecology* 44: 35 – 45.

Siregar, E. H., Atmowidi, T., and Kahono, S. (2016). Diversity and Abundance of Insect Pollinators in Different Agricultural Lands in Jambi, Sumatera. *HAYATI Journal of Biosciences* 23(1): 13–17.

Ssymank, A., Kearns, C. A. and Pape, T. (2007). Pollinating Flies (Diptera): A major contribution to plant diversity and agricultural production. *Biodiversity* 9(2): 86 – 89.

Thiemann, T. C., Lemenager, D. A., Kluh, S., Carroll, B. D., Lothrop, H. D., and Reisen, W. K. (2012). Spatial Variation in Host Feeding Patterns of Culex tarsalisand the Culex pipiens complex (Diptera: Culicidae) in California. *Journal of Medical Entomology* 49(4): 903–916.

Wiegmann, B. M., Trautwein, M. D., Winkler, I. S., Barr, N. B., Kim, J. W., Lambkin, C., and Yeates, D. K. (2011). Episodic radiations in the fly tree of life. *Proceedings of the National Academy of Sciences* 108(14): 5690-5695.

Willmer, P. (2011). Pollination and floral ecology. *Plant Science Bulletin* 57(4):163-165

Xue, R.-D., Ali, A., and Barnard, D. R. (2008). Host species diversity and post-blood feeding carbohydrate availability enhance survival of females and fecundity in Aedes albopictus *(Diptera: Culicidae)*. *Experimental Parasitology* 119(2): 225–228.

CHAPTER THREE

3.0 Diversity and Species Composition of Flower Visiting Flies Associated with Cucurbitaceous Production Systems in Morogoro region, Eastern-Central Tanzania

S.A. Kabota[1*], **M. W. Mwatawala**[1], **M De. Meyer**[2] and **K. Jordaens**[2]

[1]Department of Crop Science and Horticulture, Sokoine University of Agriculture (SUA), P. O. Box 3005 Chuo Kikuu, Morogoro, Tanzania,

[2]Royal Museum for Central Africa, Invertebrates Section and JEMU, Leuvensesteenweg 13, B3080 Tervuren Belgium.

Corresponding author, e-mail: sijakabota@gmail.com

To be submitted to the Journal of Insect Science (OXFORD)

3.1 Abstract

Flower vising flies are among the dipteran group of agricultural importance. Little was known about the diversity and species composition of flower visiting flies associated with cultivated cucurbit crops in Tanzania prior to this study. Understanding the diversity and species composition of flower vising flies could be of great help in designing sustainable field pollinator conservation management strategies. This study was carried out from March 2020 to July 2020 in the plateau and mountainous zone of the Morogoro region to investigate flower visiting flies community structure in cultivated cucurbit crops. Flies were trapped using yellow pan traps and hand net from ten established cucurbit fields. A total of 7 606 flies belonging to 22 morphospecies were collected. 77.58% of the individuals were collected from the mountainous zone while the remaining 22.42% were collected from the plateau zone. Both Shannon, Simpson and Margalef indexes placed the mountainous zone as the most abundant and species rich zone in term of number of species. Species abundance distribution models indicated hierarchically arrangement of flower visiting fly's communities within cucurbit crops. All fields were highly similar as most of the species were shared between fields within each zone.

Keywords: Diversity, Species composition, Flower vising flies, Cucurbit crops

3.2 Introduction

Flower visiting flies play many crucial ecological service roles in the ecosystem (Genung *et al.*, 2017), including the pollination of more than 19% of flowering plants (Banerjee, 2016). Flower visiting flies pollinate more than 100 cultivated crops of such economic importance such as cacao, cashew, tea, apple, onion, strawberry, tomato and pepper (Bashir *et al.*, 2019). About 71 Diptera families contain species that partly visit or pollinate at least 555 flowering plants of which some are of agricultural importance (Ssymank *et al.*, 2007; Gervais *et al.*, 2018), and their visitation to these crops contribute up to 35% of the total food production volume worldwide (Banerjee, 2016; Peters *et al.*, 2016).

Currently, the trends of pollinator decline in agro-ecosystems have raised concern all over the world (Orford *et al.*, 2015, Reis *et al.*, 2019). More attention has been on productivity of pollinator-dependents crops such as cucurbits (Lautenbach *et al.*, 2012). The decreases in diversity and abundance of such important pollinators as bees and flies compromises the production of cucurbit crops such as watermelon, squash, pumpkin and cucumbers (Mokam *et al.*, 2014; Walters 2016). Majority of cucurbit crops rely on insect pollination for their reproduction success (Walters, 2016). Thus insufficient pollination services could result up 90% fruit loss in these crops (Lautenbach *et al.*, 2012) and ultimately endangering the source of food and the sustenance of general economy of small scale farmers in Tanzania (Classen *et al.*, 2015; Sawe *et al.*, 2020a).

In the Tanzania, flower visiting flies are diverse and widely are distributed throughout the country (Sawe *et al.*, 2020b). The country harbors a variety of flies (Sawe *et al.*, 2020a). However, loss of important pollinator communities continues to be a major threat to biodiversity ecosystems and the production of many important crops (Classen *et al.*, 2015; Sawe *et al.*, 2020a). Evidence from the few pollinator studies that have been conducted (Peters *et al.,* 2016; Sawe *et al.,* 2020a, Sawe *et al.,* 2020b) indicate the probability of Tanzania's ecosystem to harbor a vast majority of flower visiting flies although their diversity and species composition is poorly described. Few works have been done on insect pollinators in Tanzania except those conducted by Sawe *et al.* (2020a) and Sawe *et al.,*(2020b) which mainly focused on hand and insect pollination of a single cucurbit crop (*Citrullus lanatus Thunb.*). These studies generally only quantified the floral visitation rates of wild honeybees, hoverflies and hand pollination of watermelon flowers in the Arusha and Kilimanjaro area. Therefore, the conservation status of many species of flower visiting flies as flower visitors or pollinators of cucurbit crops remains poorly documented in Tanzania. Thus the present study focused to assess the patterns of community structure and species composition of flower visiting flies associated with three cucurbit crops (*Cucumis sativus L.)*, (*Citrullus lanatus)* and (*Cucurbita moschata* D.). The results from this study provide information that could assist in designing of sustainable conservation measures for Diptera pollinators.

3.3 Materials and methods

3.3.1 Study site

Studies were conducted in two agro-ecological zones of the Morogoro region, Eastern-Central Tanzania namely, Plateau zone and Mountainous zone (Anon, 2002). The plateau zone is located between 300–600 m above the sea level with average rainfall ranging between 700 mm–1200 mm per annum while the mountainous zones is located above 600 m above the sea level with average rainfall ranging from 800 mm to 2500 mm per annum (Anon, 2002). The Morogoro region is located in the transition zone between the bimodal and unimodal rainfall belts at S5°58'- S10°0'South and E35°25'- E38°30' East (United Republic of Tanzania, 2002). A total of ten (10) cucurbit fields were established from two different agro ecological zones as presented in the table 3.1. Five plots (replicates) each measuring 1 acre (4047m^2), were established in each of the two agroecological zones. Distance between plots was at least 1 km. The plots were divided into four subplots in which Three cucurbit crop species; (*Cucumis sativus L.*, *Citrullus lanatus Thunb.*, and *Cucurbita moschata* D.) were planted at a spacing of 50 cm x 60 cm, 1m × 1.5 m and 1 m × 1.5 m respectively, each in a 0.25 acre (1012m^2)subplot.

Table 3.1: Locations of experimental fields in the two different agro ecological zones of the Morogoro region

Location of field plots in two different Agro ecological zones			
Plateau zone	**Coordinates**	**Altitudes**	Low altitude area
1. SUA Horticulture Unit	S06˚50'41.4" E 37˚39'43.3"	524 m	
2. SUA Crop Museum	S06˚51'00.53" E 37˚39'17.90"	528 m	
3. SUGECO	S06° 50′ 22” E 37° 38′ 42.2”	511 m	
4. SUA Mazimbu	S06˚47'26.208" E 37˚38'7.926"	486 m	
5. SUA Mafiga	S06˚50'22.764" E 37˚37'53.46"	503 m	
Mountainous zone			High altitude area
1. Morning Site	S06° 53′ 17.9” E37° 40′ 14.93”	1274 m	
2. Mkumbulu	S06˚52'24.2" E 37˚40'21.5"	1105 m	
3. Ruvuma	S06˚52'34.6", E 37˚40'3.7"	995 m	
4. Kifuru	S06˚53'32.1" E 37˚40'9.5"	1418 m	
5. Mgola	S06˚51'41.4" : E 37˚40'4.3"	1084 m	

3.3.2 Sampling method

Sampling of flower visiting flies started when crops were at least at 10% flowering stage following the methodology developed by Mokam *et al.* (2014) with some modifications. Modification involved the use of two standardized protocols. Yellow pan traps and a hand net were used to collect flower visiting flies from the ten established cucurbit fields. Hand nets were used to collect flower visiting flies attending flowers during anthesis (i.e when flowers are fully open and functional for attracting diurnal insects) along 5 m transects. The collected flies were sorted, pinned and labeled indicating locality, date and host crop. A total of 16 yellow pan traps were uniformly distributed in each field.

About three quarters of each pan trap was filled with clean water containing a few drops of detergent to reduce surface tension. Trapping continued throughout the flowering period and trapped flies were collected into vials containing 70% ethanol. Sorting of specimens was carried out at the Sokoine University of Agriculture (SUA) Entomology Laboratory. Identification of specimens to family level was done using standard keys descried by Kirk-Spriggs and Sinclair 2017 and Marshall and Kirk-Spriggs 2017 while identification to species levels was done using keys described by Coe, 1953; Gilbert, 1986; Tschorsnig and Herting, 2001; Couri *et al.*, 2012; Whitworth, 2014; Ball and Morris, 2015; Willcox *et al.*, 2019; Thomson, 2019; De Meyer *et al.*, 2020). Representative specimens of each morphospecies were sent to the Royal Museum for Central Africa (RMCA), Tervuren, Belgium, for further identification and confirmation.

3.3.3 Data collection

Trapped insects were counted and recorded at two days intervals and then pooled together to form a weekly catch. The recorded data included number of individual species per trap per week.

3.3.4 Statistical analysis

Data were organized and managed using Microsoft excel before being used to different estimators of species diversity and richness. Determination of minimum number of species required as a representative sample of flower visiting flies in the plateau and mountainous zones was done by extrapolating species accumulative curves (SACs) based on individual-based rarefaction with 100 randomizations as described by Colwell *et al.* (2012). Three non-parametric abundance-based Estimators ABE (Abundance-based Coverage Estimator ACE, Chao 1, and Jackknife 1) were employed to estimate the minimum sampling effort satisfactory to obtain asymptote species richness and number of species associated with cucurbit crops at each field as descried by Chao and Lee 1992; Chao *et al.,* 2000; and Chao and Shen 2004.

Species abundance distribution (SADs) models based on relative abundance of species were computed to provide a quick and easy way of describing the pattern of community structures of flower visiting flies associated with cucurbit crops. The best model was selected based on the lowest value of the Akaike Information Criterion (AIC) of the model. The estimations of species richness, sampling effort and fitting of models were done using EstimateS software version 9.1.0 (Colwell, 2019), while the AIC values were computed from the radfit function found in the diversity vegan package in the R- software version 3.5.2 (R Core Team 2018).

The models used were as follow;-

i) Dominance-Preemption (Tokeshi1990) model $a_r = J\alpha(1-\alpha)^{(r-1)}$ …………… (1)

ii) Log normal (Preston 1948, 1962) model $a_r = e^{(\log(\mu) + \log(\sigma)N)}$ ………. (2)

iii) Zipf (Zipf 1949) model $a_r = J(p1)r^{\gamma}$ ………………………………………… (3)

iv) Mandelbrot (Mandelbrot 1965) model $a_r = Jc(r+\beta)^{\gamma}$………………………………(4)

Whereas *J* = abundance; α = decay rate of abundance per rank, *N* = normal deviate; μ = mean, $\log_e$ (abundance); σ = standard deviation, species; γ = decay coefficient, p1 = fitted proportion of most abundant, *c* = meaningless scaling constant, β = deviation below the asymptote described by γ, a_r = represents the expected abundance *a* of species at rank *r*.

Shannon and Simpson index of diversity as well as evenness index of Pielou were used to assess the alpha diversity of the flower visiting flies associated with cucurbit crops based on both rare and common (dominant) species. Furthermore, the Margalef index was used to highlight the most species-rich field. These were determined as follows;

i. Shannon diversity index (Shanon-Wiener, 1949) (H´ = $\sum_{i=1}^{S} \frac{¿}{N} \ln \frac{¿}{N}$)………(1)

ii. Simpson index (Simpson,1949) (D = $\sum_{i=1}^{S} \frac{¿}{N} (\frac{¿-1}{N-1}$))………………..(2)

iii. Pielou index of evenness (Pielou, 1966) (J = $\frac{H'}{\ln S}$) …………………………….

(3)

iv. Margalef index of species richness (Margalef,1958) (DMg =¿))…………….(4)

In these formulae, *ni* is the number of individuals of each of the i^{th} species in the sample; N the total number of individuals in the habitant; S the number of species in the habitant and ln, the natural logarithm. The diversity indexes were computed using the PAleontological STatistics software (PAST) Version 3.17 (Hammer, 1999-2017).

The species composition of the different cucurbit fields was measured using beta diversity indices including the Jaccard and Sorensen indices. These indices were calculated according to the formulae provided by Magurran (1988). The indices are equal to 1 when there is complete similarity and approaches 0 if the fields which have no species in common. The following are the formulae used;-

i) Sorensen's coefficient ($Sc¿=\frac{a+b}{2c+a+b}$ …………………………………….(1)

ii) Jaccard index $(jc)=\frac{b+c}{a+b+c}$ ………………………………………….(2)

Whereas Sc is a Sorensen's coefficient, *a* and b represent the number of unique species in the first and second field respectively, while c represented the number of shared species and jc is Jaccard dissimilarity indices.

3.4 Results and discussion

3.4.1 Results

3.4.1.1 Sampling effort

Results showed that sampling effort was above 90% for all study sites (Table 3.3). These result reveal that the sampling effort was sufficient to obtain a representative sample size for each filed. Hence, few species remained un sampled. Based on the species accumulative curves, the asymptote species richness were reached when the total number of individuals were 300 for Mazimbu, 380 for Horticulture unit and Crop museum, 600 for Kifulu, 1 380 for Ruvuma, 1 460 for Mgola and 1 600 for Mkumbulu. However, for the three remaining fields (Mafiga, SUGECO and Morning side), the asymptotic level was not reached (Figure 3.1).

3.4.1.2 Species diversity and richness

A total of 7 606 specimens were collected from the ten established cucurbit fields between March and July 2020 (Table 3.2). Of these, 42.4% belonged to *Musca domestica* while the second and third most abundant species were *Sarcophaga* sp1 and *Stomoxys calcitrans*, representing 20.2% and 12.9% of the specimens, respectively. The total number of all remaining flies constituted less the 25% of the total catch. The SUA horticulture unit and Morning side fields showed the highest species diversity, with 21 species found at each field, followed by the Mgola and Mkumbulu fields, each with 20 species, SUGECO and Kifulu with 19 species each, the Crop museum field with 18 species and Ruvuma field with 17 species (Table 3.2).

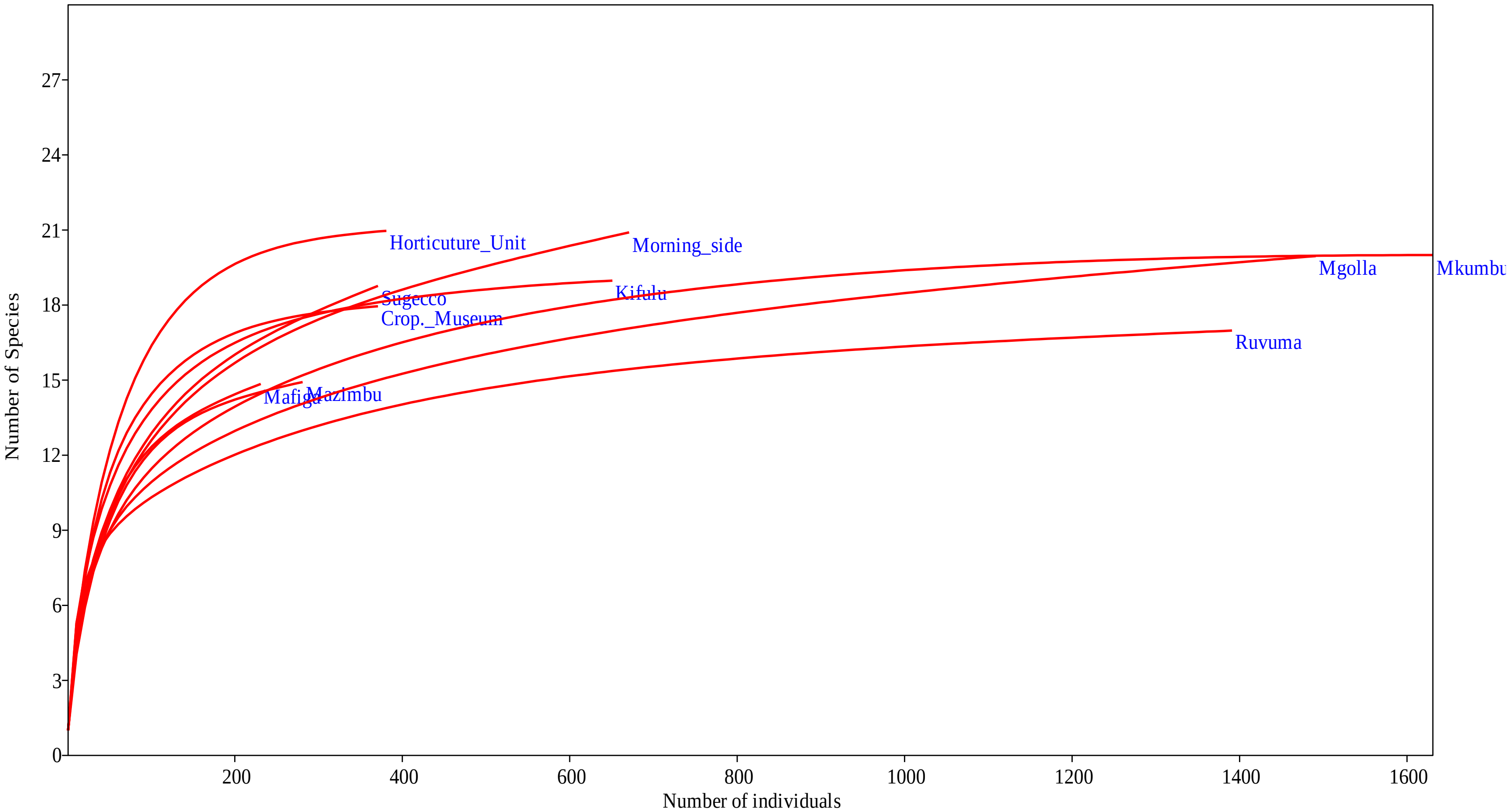

Figure 3.1: Species accumulative curves based on the number of species and number of flower vising flies individuals collected in the plateau and mountainous zone of the Morogoro region, Tanzania

Table 3.2: Numbers of different flower visiting flies (%) associated with cucurbit crops in the Morogoro region, Tanzania

Pollinators/Fields	CM	HT	MF	MZ	SU	KF	MG	MK	MOR	RU	Total
Number of species	18	21	15	15	19	19	20	20	21	17	22
Lucilia sericata	0.2	0.1	0.0	0.0	0.2	0.2	0.7	0.5	0.2	0.7	2.7
Chrysomya sp1	0.0	0.1	0.0	0.1	0.1	0.3	0.9	1.0	0.3	1.8	4.7
Lucilia cuprina	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.2
Calliphora vicina	0.1	0.1	0.0	0.0	0.0	0.6	1.2	0.7	0.2	1.4	4.3
Neomyia viridescens	0.1	0.0	0.0	0.1	0.0	0.2	0.7	0.5	0.2	0.5	2.4
Stomoxys calcitrans	0.2	0.6	0.3	0.2	0.5	1.2	3.0	3.1	1.5	2.2	12.9
Musca domestica	3.1	2.9	1.9	2.5	3.0	3.4	6.5	9.4	3.8	5.9	42.4
Graphomyia sp1	0.1	0.0	0.0	0.0	0.0	0.2	0.2	0.3	0.1	0.1	1.0
Tachina sp1	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.2	0.1	0.1	0.5
Strongyloneoura sp1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.5	0.3	0.8	2.3
Sarcophaga sp1	0.3	0.3	0.3	0.4	0.4	1.8	5.5	4.9	1.9	4.5	20.2
E. megacephalus	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.9
Syritta flaviventris	0.1	0.0	0.1	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.5
Paragus borbonicus	0.0	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.4
Syritta fasciata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Phytomia curta	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.2
Toxomerus floralis	0.2	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.0	0.0	0.9
Allograpta sp1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Mesembrius caffer	0.1	0.2	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.6
Eumerus sp1	0.2	0.1	0.1	0.1	0.4	0.1	0.4	0.1	0.0	0.0	1.5
Agromyzidae sp1	0.1	0.1	0.0	0.0	0.0	0.2	0.1	0.1	0.1	0.1	0.7
Simuliid sp1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.1	0.0	0.5
Total	5.1	5.2	3.2	3.8	5.1	8.7	19.8	21.6	9.0	18.5	100.0

CM; Crop Museum, HT; Horticulture Unit, MF; Mafiga, MZ; Mazimbu , SU; SUGECO, KF; Kifulu, MG; Mgola, MK; Mkumbulu, MS; Morning side, RU; Ruvuma

Table 3.3: Estimators of species richness based on abundance of flower visiting flies associated with cucurbit crops in the plateau and mountainous zone of the Morogoro region, Tanzania from March to July 2020

Species richness Estimators	Crop Museum	Horticulture Unit	Mafiga	Mazimbu	SUGECCO	Kifulu	Mgola	Mkumbulu	Morningside	Ruvuma
Sobs (Mao Tau)	**18[a](16.3-18.5)[b]**	**20[a](18.9-20.4)[b]**	**21[a](20.1-21.1)[b]**	**21[a](20.8-21.5)[b]**	**21[a](21.3-21.7)[b]**	**21[a](21.6-21.8)[b]**	**21[a](21.8-21.9)[b]**	**21[a](21.9-21.9)[b]**	**22[a](22-22)[b]**	**22[a](22-22)[b]**
ACE mean	20.41	21.52	22.03	22.21	22.28	22.16	22.15	22.16	22.06	22
Chao1 mean	20.31	20.98	21.44	21.69	21.88	21.90	21.95	21.98	22	22
Jack 1 mean	18.62	22.31	22.67	22.76	22.69	22.55	22.39	22.29	22.11	22.01
Mean of three ABE	**19.78**	**21.60**	**22.05**	**22.22**	**22.28**	**22.20**	**22.16**	**22.14**	**22.06**	**22.04**
Sampling effort %	**91**	**97.22**	**95.2**	**94.51**	**94.25**	**94.59**	**94.77**	**94.85**	**99.72**	**99.82**

Sobs, species richness observed generated per Mao Tau in EstimateS software.
[a]Mean value of Sobs, [b]Lower-upper bound of the Sobs values.
ACE: Abundance Coverage Estimator
ABE: Abundance Based Estimator

Table 3.4: Species diversity and species richness indices of flower visiting flies associated with cucurbit crops in the plateau and mountainous zone of the Morogoro region, Tanzania, from March to July 2020

Fields	Crop museum	Horticulture Unit	Mafiga	Mazimbu	SUGECCO	Kifuru	Mgola	Mkumbulu	Morning side	Ruvuma
Simpson_1-D	0.6216	0.6649	0.6163	0.5505	0.6367	0.78	0.781	0.734	0.7442	0.8039
Shannon_H	1.685	1.822	1.56	1.412	1.625	1.967	1.85	1.746	1.801	1.915
Evenness_e^H/S	0.2995	0.2945	0.3172	0.2736	0.2674	0.3761	0.3179	0.2866	0.2884	0.3992
Margalef	2.852	3.348	2.549	2.466	3.018	2.769	2.597	2.566	3.064	2.208

Table 3.5: Jaccard indices of the flower visiting flies at the different fields studied in the plateau and mountainous zone of the Morogoro region, Tanzania

Zones	Fields	CM	HT	MF	MZ	SU	KF	MG	MK	MS
Plateau zone	Crop. Museum									
	Horticulture Unit	0.650								
	Mafiga	0.705	0.737							
	Mazimbu	0.705	0.722	0.681						
	Sugecco	0.667	0.656	0.722	0.706					
Mountainous zone	Kifulu	0.672	0.698	0.648	0.722	0.727				
	Mgola	0.661	0.667	0.636	0.655	0.678	0.661			
	Mkumbulu	0.661	0.683	0.636	0.643	0.667	0.678	0.667		
	Morning side	0.700	0.672	0.737	0.732	0.737	0.689	0.672	677.000	
	Ruvuma	0.667	0.644	0.700	0.722	0.706	0.655	0.649	0.649	0.644

CM; Crop Museum, HT; Horticulture Unit, MF; Mafiga, MZ; Mazimbu , SU; SUGECO, KF; Kifulu, MG; Mgola, MK; Mkumbulu, MS; Morning side, RU; Ruvuma

Table 3.6: Sorensen indices of flower visiting flies in the plateau and mountainous zone of the Morogoro region, Tanzania

Zone	Fields	CM	HT	MF	MZ	SU	KF	MG	MK	MS
Plateau zone	Crop. Museum									
	Horticulture Unit	0.481								
	Mafiga	0.478	0.462							
	Mazimbu	0.478	0.500	0.469						
	Sugecco	0.481	0.459	0.459	0.478					
Mountainous zone	Kifulu	0.468	0.465	0.459	0.459	0.447				
	Mgola	0.473	0.482	0.467	0.447	0.475	0.494			
	Mkumbulu	0.475	0.482	0.466	0.455	0.481	0.494	0.500		
	Morning side	0.482	0.488	0.462	0.474	0.462	0.488	0.506	0.494	
	Ruvuma	0.479	0.475	0.471	0.500	0.457	0.486	0.481	0.481	0.475

CM; Crop Museum, HT; Horticulture Unit, MF; Mafiga, MZ; Mazimbu , SU; SUGECCO, KF; Kifulu, MG; Mgola, MK; Mkumbulu, MS; Morning side, RU; Ruvuma

The Mazimbu and Mafiga fields had the lowest diversity with 15 species found at each field (Table 3. 2). Twelve species occurred in all fields; *Lucilia sericata*, *Chrysomya* sp1, Simuliid sp1, *Neomya viridescens*, *Stomoxys calcitrans*, *Musca domestica*, *Strongyloneoura* sp1, *Sarcophaga* sp1, *Eristalinus megacephalus*, *Syritta flaviventris*, *Toxomerus floralis* and *Eumerus* sp1. The other remaining species were found in either fields among the ten established cucurbit fields.

The Shannon and Simpson diversity indices both ranked the communities of Kifulu, Ruvuma Mgola, Horticulture unit, Morning side and Mkumbulu as the most diverse fields compared to Crop museum, SUGECO, Mafiga and Mazimbu which had relatively small values of Shannon and Simpson index (Table 3.4). Evenness values showed a considerable differences in abundance distribution of flower visiting flies among the fields in the plateau and mountainous zones. The highest evenness value was recorded at Ruvuma (0.399), followed by Kifulu (0.3761), Mgola (0.3179) and Mafiga (0.3172) while the lowest value was obtained at SUGGECO (0.2674), Mazimbu (0.2736), Mkumbulu (0.2866) and Morning side (0.288).

Based on both Jaccard and Sorensen indices, flower visiting flies communities in all fields were highly similar in term of species composition. The Jaccard indexes ranged from 0.632 to 0.737 while the Sorensen index ranged from 0.455 to 0.506 (Table 3.5 and 3.6). Levels of species similarity between the fields in the plateau zone were all >0.6 (Table 3.5). The highest similarity was observed between Mafiga, Mazimbu and SUGECO on the one hand and Crop museum and horticulture unit on the other hand (all > 0.6). All these are fields found on the plateau zone. Similarly, for the mountainous zone the similarity index values between fields were > 0.6. However, highest similarity was recorded when three fields (Mafiga, Mazimbu and SUGECO) from plateau zone compared with fields from the mountainous zone which gave the similarity index values above 0.6. All fields in the mountainous zone gave similarity values ranging from 0.644 to 0.711. Moreover, the Sorensen indexes (0.481-0.5) indicated the same trends of highly similarities among fields in the mountainous zone (Table 3.6).

3.4.1.3 Pattern of community structure

Based on the AIC values (Table 3.7) and SADs (Figures 3.2 and 3.3), the pattern of community structure of flower visiting flies associated with cucurbit crops in the plateau zone were best described by Zipf and Zipf-Mandelbrot models (Lowest AIC values). In the mountainous zone however, the community structure of the flower visiting flies associated with cucurbit crops differed considerable among fields. The pattern of community structures of Kifulu, Mgola, Mkumbulu and Morning side were best described by Zipf-Mandelbrot models while that of Ruvuma field was best described by Dominance-Preemption model.

The Zipf and Zipf-Mandelbrot models characterized the nine fields (Crop museum, Horticulture Unit, Mafiga, Sugecco and Mazimbu, Kifulu, Mgola, Mkumbulu and Morning side) as habitats in which the communities are hierarchical in structure (The species communities are organized into orders of rank) while the Preemption model characterized the Ruvuma field as a habitat in which most of the least abundant species are evenly distributed within the communities. SADs also showed the predominance of *M. domestica*, which accounted for 42.44% of all Diptera collected (Table 3. 2). Indeed, the species was abundant in all fields throughout the sampling period. Other species which were abundant included *Sarcophaga* sp1 that accounted for 20.25% of the total specimens, followed by *Stomaxys* sp1 which represented 12.9% of the total number of Diptera collected (Table 3.2)

Table 3.7: Values of AIC for each rank-abundance distribution model of flower visiting flies associated with cucurbit crops in the plateau and mountainous zone of the Morogoro region

	AIC value in each survey cucurbit field									
Species Abundance Models	Crop Museum	Horticulture Unit	Mafiga	Mazimbu	SUGECCO	Kifulu	Mgola	Mkumbulu	Morning side	Ruvuma
Null	387.7	398.6	222.6	318.7	397.3	364.8	986.1	1255.1	567.6	584.3
Preemption	300.5	309.5	144.5	202.7	203.7	170.0	155.9	260.2	184.9	117.6a
Lognormal	162.5	154.5	84.0	106.6	101.4	116.7	300.1	189.5	140.5	236.5
Zipf	128.8a	109.9a	70.4a	79.4a	89.1a	127.2	435.9	251.8	159.9	386.7
Mandelbrot	130.8a	111.9a	72.4a	81.4a	91.1a	104.5a	148.9a	139.7a	119.9a	NA

Value with a letter represent the lowest values of the AIC.
AIC; Akaike Information Criterion

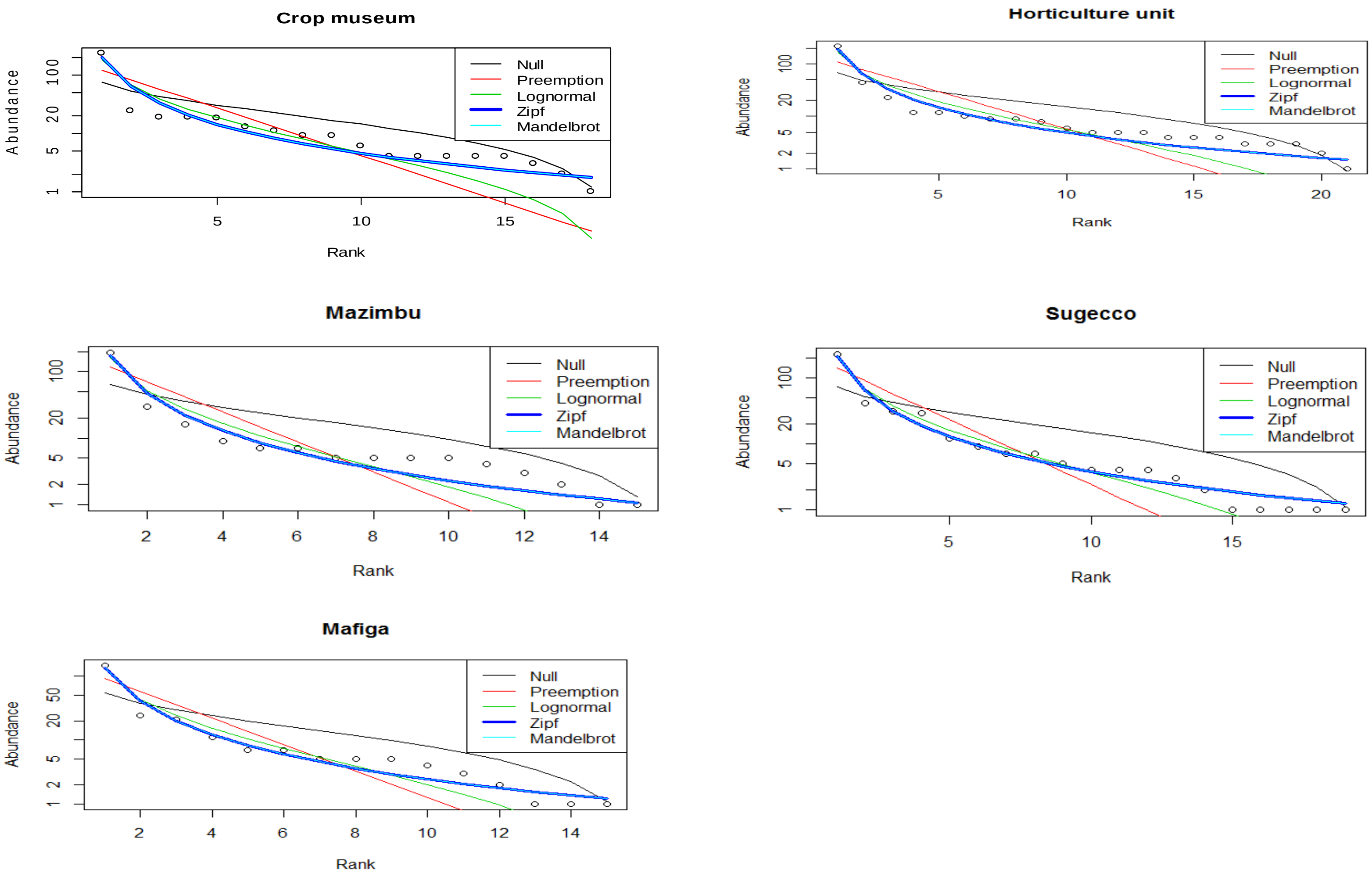

Figure 3.2: SAD model of flower visiting flies associated with cucurbit crops in the plateau zone of the Morogoro region, from March to July 2020. The different colors represent different models

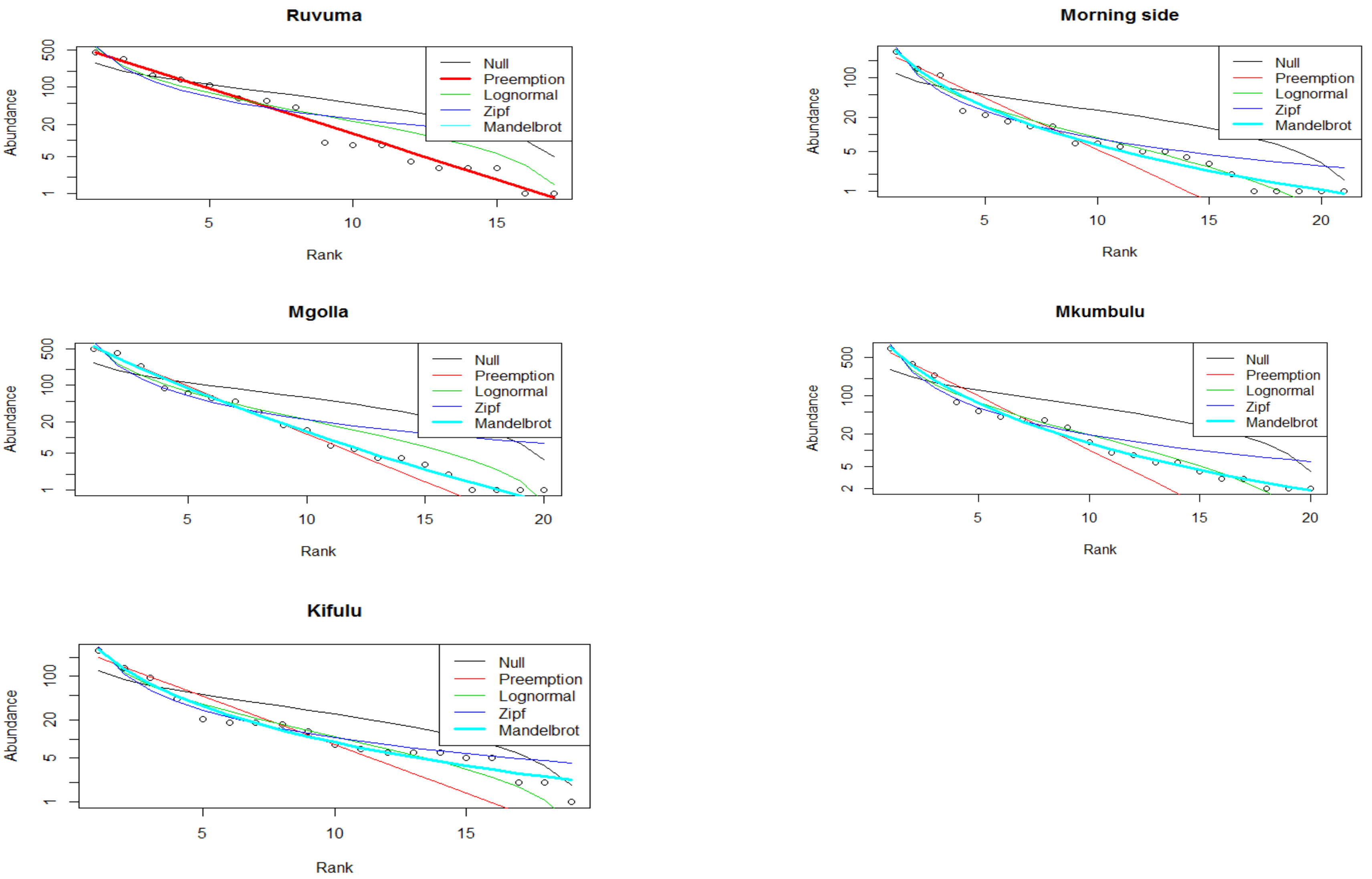

Figure 3.3: SAD model of flower visiting flies associated with cucurbit crops in the Mountainous zone of the Morogoro region, from March and July202. The different colors represent different models

3.4.2 Discussion

The sampling effort employed in this study was sufficient to obtain reliable estimates of flower visiting flies' diversity in the study fields. The maximum number of individuals required to acquire asymptotic species richness was 1642 individuals and the minimum number was 243 individuals corresponding to the asymptotic levels of 15 to 21 species per field. At least three fields in each mountainous and plateau zones provided sufficient number of individuals (asymptotic species richness) for the study. More than 90% of significant flower visiting flies of cucurbit crops were collected and the actual diversity missing is probably the more rare species of no major impact in cucurbit pollination. The findings are similar to those by Mokam *et al.* (2014) who reported the convectional accepted number of samples is 20. Yet, the results also indicated that some species were not samples. However, collecting all species in the ecosystem is practically impossible, as these ecosystems comprise high diversity of species and most of them are rare.

Based on the AIC values, the flower visiting flies' communities in the plateau zone (Crop museum, Horticulture unit, SUGECO, Mafiga and Mazimbu) the best fit was obtained with the Zipf model while those fields from the mountainous zone (Mgola, Mkumbulu, Morning side and Kifulu) the best fit was obtained with the Zipf-Mandelbrot model with exception with the Ruvuma which the best fit was obtained with the Preemption model. The Zipdf and Zipf-Mandelbrot models are close related and provide a best description of the community structure of the flower visiting flies associated with cucurbit crops. The two models indicated that all flower visiting flies species got established simultaneously in the communities and in temporal succession some few species such as *M. domestica*, *S. calcitrans* and *Sarcophaga* sp1 became more dominant than others. The Preemption model further indicated that the rare species were least even distributed in the community and preempting more than 50% of the smallest remaining resources upon each new species establish in the community. Therefore the communities were hierarchically in structures. Similar results were reported by Mokam *et al.* (2014) and Su (2018) who reported that insect communities appears to be hierarchical structured with a high predominance of few generalist species.

Results from this study indicate that the diversity and species richness of flower visiting flies communities varied among fields. According to Khairiyah *et al.* (2013), sites with diversity values between 0 and 2.4 are categorized as low diverse sites while those with diversity values between 2.5 and 3.5 are moderate diverse site; if the diversity value is >3.5 sites are considered as highly diverse. Based on Khairiyah *et al.* (2013) categorizations, all ten cucurbit fields were less diverse for flower visiting flies since the diversity values ranged from 0.1 to 1.965 during the dry and wet seasons. This could be due to less variations in climatic conditions and in some extent on vegetation cover among the two zones during the study period. The results were not in accordance with the findings by Mokam *et al.* (2014) and Okrikata and Yusuf (2019), who reported significant variation in diversity index values of insects associated with cucurbit crops, and vegetation, in different agro-ecological zones of Cameroon.

Fields from mountainous zone were notably slightly diverse in flower visiting flies compared with the fields in the plateau zone. Ruvuma and Kifulu were highly diverse fields while Morning side was the species richest field in the mountainous zone compared with the other two (Mkumbulu and Mgola) fields. This is most likely due to its closer proximity of natural habitats (Uluguru mountains forest) that could be a source for the higher diversity, and the presence of cool climatic condition that support the reproduction success and survive of flower visiting flies. Vergara and Badano (2009) reported that variation of diversity indices among the insect pollinators were linked with altitudinal gradients and seasons. On the other hand, cucurbit fields in the Plateau zone had very low diversity values and relative high species richness values at SUGECO and Horticulture Unit. Apparently, the plateau sites which are largely in a landscape that is predominated by agriculture and semi—urban infrastructure present homogeneity habitants that could be possible causing a barrier for reproduction, distribution and establishment of different species of flower visiting flies.

Moreover, the evenness index indicated a uniform distribution of flower visiting flies in all fields. Four fields showed a high evenness index (Mafiga, Kifulu, Mgola and Ruvuma) while evenness indices were much lower in the other six fields. This implies that flower visiting flies differs in distribution patterns between the plateau and mountainous zone.

3.5 Conclusion

Agroecological zones seemed to be the primary determinant of flower visiting flies diversity in the agroecosystem. Flower visiting flies communities showed high taxonomic richness and diversity all over the study period. This study provides the first baseline ecological information on diversity of pollinating flies of the plateau and mountainous zone of the Morogoro region in Tanzania. Findings of this study represent an asset for the understanding of pollinating flies communities associated with cucurbit crops and deepen our knowledge on the best way to manage agro-ecosystems and ultimately conserve its flora and fauna, especially for the group of flies which remains poorly known in Tanzania ecosystems.

References

Ball, S. and Morris, R. (2015). *Britain's Hoverflies a Field Guide*. (2nd Ed.) Princeton University Press, Princeton. 312pp.

Banerjee, D. (2016). A Report on Flies (Diptera : Insecta) as flower visitors and pollinators of Kolkata and it's adjoining Areas. *Records of the Zoological Survey* 105(4): 1 – 7.

Bashir, M. A., Saeed, S., Sajjad, A., Khan, K. A., Ghramh, H. A., Shehzad, M. A., Mubarak, H., Mirza, N., Mahpara, S., Rehmani, M. I. A. and Ansari, M. J. (2019). Insect pollinator diversity in four forested ecosystems of southern Punjab, Pakistan. *Saudi Journal of Biological Sciences* 26(7): 1835 – 1842.

Belamkar, N. V. and Jadesh, M. (2012). A preliminary study on abundance and diversity of insect fauna in Gulbarga District, Karnataka, India. *International Journal of Science and Research* 3(358): 1 – 6.

Belamkar, N. V. and Jadesh, M. (2014). A preliminary study on abundance and diversity of insect fauna in Gulbarga District, Karnataka, India. *International Journal of Science and Research* 3(12): 1670 – 1675.

Boulter, S. L., Lambkin, C. L. and Starick, N. T. (2011). Assessing the abundance of seven major arthropod groups along an altitudinal gradient and across seasons in subtropical rainforest. *Memoirs of the Queensland Museum* 55(2): 303 – 313.

Chao, A., and Lee, S. M. (1992). Estimating the number of classes via sample coverage. *Journal of the American statistical Association* 87(417): 210 – 217.

Chao, A., and Shen, T. J. (2004). Nonparametric prediction in species sampling. *Journal of Agricultural, Biological, and Environmental Statistics* 9(3): 253 – 269.

Chao, A., Hwang, W. H., Chen, Y. C., and Kuo, C. Y. (2000). Estimating the number of shared species in two communities. Statistica sinica 10: 227 – 246.

Classen, A., Eardley, C. D., Hemp, A., Peters, M. K., Peters, R. S., Ssymank, A. and Steffan-Dewenter, I. (2020). Specialization of plant–pollinator interactions increases with temperature at Mt. Kilimanjaro. *Ecology and Evolution* 11: 2182 – 2195.

Coe, R. L. (1953). Diptera – Syrphidae. In Handbooks for the identification of British insects. *Royal International Entomological Society of London* 10 (1): 1 – 98.

Colwell, R. K. (2019). EstimateS: statistical estimation of species richness and shared species from samples with non-parametric extrapolation. [http://purl. oclc.org/ estimates] site visited on 15/10/2020.

Colwell, R. K., Chao, A., Gotelli, N. J., Lin, S. Y., Mao, C. X., Chazdon, R. L., and Longino, J. T. (2012). Models and estimators linking individual-based and sample-based rarefaction, extrapolation and comparison of assemblages. *Journal of Plant Ecology* 5(1): 3 – 21.

Couri, M. S., De Carvalho, C. J., and Pont, A. C. (2012). Taxonomy of the Muscidae (Diptera) of Namibia: a key to genera, diagnoses, new records and description of a new species. *African Invertebrates* 53(1): 47 – 67.

Courtney, G. W., Pape, T., Skevington, J. H. and Sinclair, B. J. (2009). Biodiversity of Diptera. Blackwell Publishing, Canada. 38pp.

Gae, D. and Djie, C. (2014). Patterns of species richness and diversity of insects associated with cucurbit fruits in the Southern Part of Cameroon. Journal of Insects Science 14 (1): 1 – 9.

Genung, M. A., Fox, J., Williams, N. M., Kremen, C., Ascher, J., Gibbs, J. and Winfree, R. (2017). The relative importance of pollinator abundance and species richness for the temporal variance of pollination services. Ecology 98(7): 1807 – 1816.

Gervais, A., Chagnon, M. and Fournier, V. (2018). Diversity and pollen loads of flower flies (Diptera : Syrphidae) in Cranberry Crops. Annals of the Entomological Society of America 8: 1–9.

Gilbert, F.S. (1986). *Hoverflies. Naturalists' Handbook* 5. Press Syndicate of the University of Cambridge, Cambridge. 64pp.

Habel, J. C. and Ulrich, W. (2020). Ecosystem functions in natural and anthropogenic ecosystems across the East African coastal forest landscape. *Biotropica* 11: 1–10.

Hammer, O. (1999–2017). PAleontological STatistics. Natural History Museum University of Oslo, Oslo, Norway.

Kirk-Spriggs, A. H. and Sinclair, B. J. (2017). *Manual of Afrotropical Diptera Volume 2. Nematocerous Diptera and lower Brachycera*. South Africa National Biodiversity Institute, Pretoria, South Africa. 956pp.

Ladányi, M. and Horváth, L. (2010). A review of the potential climate change impact on insect populations- general and agricultural aspects. *Applied Ecology and Environmental Research* 8(2): 143 – 152.

Larson, B. M. H., Kevan, P. G., and Inouye, D. W. (2001). Flies and flowers: Taxonomic diversity of anthophiles and pollinators. *Canadian Entomologist* 133(4): 439 –465.

Lautenbach, S., Seppelt, R., Liebscher, J., and Dormann, C. F. (2012). Spatial and temporal trends of global pollination benefit. PLoS one 7(4): e35954.

Magurran, A. E. (1988). *Ecological Diversity and Its Measurement*. Princeton University Press, Croom-Helm, London. 179pp.

Margalef, R., (1958). *Temporal Succession and Spatial Heterogeneity in Phytoplankton. In Perspectives In Marine Biology*, Buzzati-Traverso (ed.). University of Califonia Press, Berkeley, pp. 323-347.

Marshall S. A. and Kirk-Spriggs, A. H. (2017). Natural history of diptera. In: Manual of Afrotropical Diptera, Introductory Chapters and Keys to Diptera Families. (Edited by Kirk-Spriggs, A. H. and Sinclair, B. J.), South Africa National Biodiversity Institute, Pretoria, South Africa. pp. 135 – 152.

Meyer, M. D. E., Goergen, G., and Jordaens, K. (2020). Taxonomic revision of the Afrotropical Phytomia Guérin-Méneville Diptera: *Syrphidae* 4803(2): 201–250.

Mokam, D. G., Djiéto-Lordon, C., Bilong, C. F. B. and Brunet, J. (2014). Patterns of species richness and diversity of insects associated with cucurbit fruits in the southern part of Cameroon. *Journal of Insect Science* 14(1): 248.

Okrikata, E. and Yusuf, A. O. A (2019). Study on the Diversity and Relative Abundance of Insect Fauna in Wukari, Taraba State, Nigeria. *International Journal of Advanced Biological and Biomedical Research* 7: 141 – 153.

Orford, K. A., Vaughan, I. P. and Memmott, J. (2015). The forgotten flies : the importance of non-syrphid Diptera as pollinators. *Proceedings of the Royal Society Biological Sciences* 282(1805): 2014 – 2934.

Peters, M. K., Ferger, S. W., Classen, A., Peters, M. K., Ferger, S. W., Helbig-bonitz, M., Schmack, J. M., Maassen, G. and Schleuning, M. (2016). *Complementary Ecosystem Services Provided by Pest Predators and Pollinators Increase Quantity and Quality of Coffee Yields Complementary Ecosystem Services Provided by Pest Predators and Pollinators Increase Quantity and Quality of Coffee Yields.* Royal Society Publishing, USA. 8pp.

Pielou, E. C., (1966). The measurement of diversity in different types of biological collections. *Journal of Theoretical Biology* 13: 131-144.

Reis, H., Martello, F., Almeida, E. A. B., Mengual, X., Harper, K. A., Campanholo, Y., Paul, J., Abbud, C. and Cezar, M. (2019). Landscape structure shapes the diversity of bene fi cial insects in co ff ee producing landscapes. *Biological Conservation* 238: 108 – 193.

Sawe, T., Eldegard, K., Totland, Ø., Macrice, S. and Nielsen, A. (2020). Enhancing pollination is more effective than increased conventional agriculture inputs for improving watermelon yields. *Ecology and Evolution* 10(12): 5343 – 5353.

Sawe, T., Nielsen, A., Totland, Ø., Macrice, S. and Eldegard, K. (2020). Inadequate pollination services limit watermelon yields in northern Tanzania. *Basic and Applied Ecology* 44: 35 – 45.

Shannon, C. E. and Wiener, W. (1949).The mathematical theory of communication. Urbana, University of Illinois Press, 177pp.

Simpson, E. H. (1949). Measurement of diversity. *Nature* 163(4148): 688 – 688.

Ssymank, A., Kearns, C. A. and Pape, T. (2007). Pollinating Flies (Diptera): A major contribution to plant diversity and agricultural production. *Biodiversity* 9(2): 86 – 89.

Su, Q. (2018). A general pattern of the species abundance distribution. PeerJ Chemistry Journals 6: 5928.

Thomson, D. M. (2019). Effects of long-term variation in pollinator abundance and diversity on reproduction of a generalist plant. *Journal of Ecology* 107(1): 491–502.

Totland, O. (1994). Influence of climate, time of day and season, and flower density on insect flower visitation in alpine Norway. *Arctic and Alpine Research* 26(1): 66–71.

Tschorsnig, H. P. and Herting, B. (2001). *The Tachinids (Diptera: Tachinidae) of Central Europe: Identification Keys for the Species and Data on Distribution and Ecology*. State Museum of Natural Science, Stuttgart. 150pp.

Vergara, C. H. and Badano, E. I. (2009). Pollinator diversity increases fruit production in Mexican coffee plantations: The importance of rustic management systems. *Agriculture, Ecosystems and Environment* 129(3): 117 – 123.

Walters, A. (2016). *Pollination in Cucurbit Crops. Handbook of Cucurbits*. Swinburne University of Technology Press. Australia. 200pp.

Whitworth, T. (2010). Keys to the genera and species of blow flies (Diptera: Calliphoridae) of the West Indies and description of a new species of Lucilia Robineau-Desvoidy. *Zootaxa* 2663: 1 – 35.

Willcox, B. K., Howlett, B. G., Robson, A. J., Cutting, B., Evans, L., Jesson, L., Kirkland, L., Jean-Meyzonnier, M., Potdevin, V., Saunders, M. E. and Rader, R. (2019). Evaluating the taxa that provide shared pollination services across multiple crops and regions. *Scientific Reports* 9(1): 1 – 10.

CHAPTER FOUR

4.0 Visitation Rates and Population Abundance of Hoverflies Foraging Cultivated Cucurbit Crops in Morogoro, Tanzania

S.A. Kabota[1*], **M. W. Mwatawala[1]**, **M De. Meyer[2]** and **K. Jordaens[2]**

[1]Department of Crop Science and Horticulture, Sokoine University of Agriculture (SUA), P.O. Box 3005 Chuo Kikuu, Morogoro, Tanzania,

[2]Royal Museum for Central Africa, Invertebrates Section and JEMU, Leuvensesteenweg 13, B3080 Tervuren Belgium.

Corresponding author, e-mail: sijakabota@gmail.com

To be submitted to the Journal of Insect Conservation (Springer)

4.1 Abstract

Several research evidences show that hoverflies is becoming increasing important for maintaining the production of many important agricultural crops. However, relatively little research on abundance and visitation rates of hoverflies associated with cultivated cucurbit crops has been conducted in Tanzania. Hoverflies provide among other ecosystem services, pollination service to a wide range of flowering plants. The goal of this study was to evaluate the seasonal visitation rates and population abundance of hoverflies associated with cucurbit crops in the plateau and mountainous zone of the Morogoro region from the month of March to July 2020. Data were obtained by conducting observational count of flower visits of hoverflies on cucurbit crop flowers along a 15 m transects. About 332 hoverfly specimens belonging to eight genera: *Eristalinus* (*Merodonoides* Curran), *Paragus* (Afroparagus Vujic and Radenkovic), *Allograpta* Osten Sacken, *Eumerus* Meigen, *Mesembriussensu stricto, Phytomia* Guérin-Méneville, *Toxomerus* Macquart, and *Syritta* Le Pelletier and Serville were collected from two cucurbit growing seasons. Among these, *Eristalinus megacephalus*, *Mesembrius caffer* and *Toxomerus floralis* were further examined because they were the most the abundant species and showed significant variation in visitation rate, foraging time and abundance across the two agroecological zones, season and sampling weeks (P<0.05). The floral visitation rates varied substantially among the dominant hoverfly species but were not influenced by seasons and the most abundant hoverfly flies contributed more on visitation activities compared to the least abundant one.

Key words: Visitation rate, Hoverflies, Cucurbit crop, Foraging time

4.2 Introduction

Pollination is a crucial ecological service for the production of many agricultural crops (Gervais *et al.,* 2018). The efficiency of pollination services depends on among other factors, the number of flower visitors and their visitation rate in the ecosystem (Johansson *et al.*, 2020). A rapid decline of flower visitors may endanger the survival and reproduction success of many ecosystem-dependent animals and plants (Gervais *et al.*, 2018). So far, more than 5% deficit in flower visitors has been reported in developing countries (Bashir *et al.,* 2019; Ssymank *et al.,* 2008). The decline is often related to changes in land-use, environmental pollution, invasive alien species, pathogens, intensified agriculture and climate change (Artins *et al.*, 2001; Johansson *et al.*, 2020).

Flower visitors are important agents for transfer of pollens that facilitates reproduction and distribution of many plants worldwide (Albano *et al.,* 2009; Bashir *et al.,* 2019; Gervais *et al.,* 2018). Indeed, their decline curtails the provision of an important ecosystem service such as pollination to more than 90% of flowering plants including global leading food crops (Aizen *et al.*, 2009; Klein *et al.*, 2007). Several studies have warned about the impacts of decline of number flower visitors in the ecosystems (Aizen *et al.,* 2009; Bashir *et al.*, 2019; Ebeling *et al.,* 2008; Sawe *et al.,* 2020; Ssymank *et al.,* 2008). Much concern is on productivity of pollinator-dependent crops including cucurbits (Bomfim *et al.,* 2016; Lautenbach *et al.,* 2012).

Decline of number of flower visitors in agro-ecosystem is often associated with reduction of visitation rate and poor pollination services (Gervais *et al.*, 2018). The impacts of lower visitation rate and poor pollination service can directly affect reproduction and yield stability of cucurbit crops (Lautenbach *et al.,* 2012; Bomfim *et al.,* 2016). In addition to lower growth rate due to low visitation rate, some pollinator- dependent plant species may become extinct (Primack *et al.,* 2015).

Many cucurbitaceous crops such as cucumber, squash, pumking and watermelon depend on insect pollination (Bomfim *et al.,* 2016). They produce colored flowers with well-exposed anthers and stigmas to easily attract flower visitors (Bomfim *et al.*, 2016). In such flowers, nectar and pollen are easily accessible by many insect species including Diptera, particularly Syrphidae (hoverflies or flower flies) (Bomfim *et al.,* 2016).

Syrphidae (Diptera) are often abundant and regular visitors of many crops, including cucurbits (Bomfim *et al.*, 2016; Sajjad and Saeed, 2010). They visit flowers mainly to obtain nectar for energy and pollen for proteins, lipids and vitamins (Artins *et al.*, 2001; Sajjad and Saeed, 2010). The frequency and pattern of visits vary among taxa, seasons and altitudes (Artins *et al.*, 2001). Season determines the availability of food by influencing the density of flowers in an agro-ecosystem (Artins *et al.*, 2001; Primack *et al.*, 2015).

Empirical studies have shown that vegetation ecosystems with high flower density attract large numbers of floral visitors including hoverflies (Artins *et al.,* 2001; Chen and Zuo, 2019; Lázaro *et al.,* 2013). Yet, patterns may differ among and within seasons and could negatively affect the relationships in specific geographical areas, crop species and altitudes (Primack *et al.*, 2015; Lázaro *et al*., 2013).

Seasons and altitude have long been recognized to influence abundance and flower visit patterns of Syrphidae of ecosystems (Lázaro *et al*., 2013). However, this has not been determined for syrphid flies foraging cucurbit crops particularly in Tanzania. Thus, the role of hoverflies in agro-ecosystems are largely unknown.

Understanding the seasonal variation in visitation rates and abundance of these flies associated with Cucurbitaceae production systems could be of great help in designing biodiversity conservation programs to cope with the current global decline of pollinators

(Classen *et al.,* 2014; Orford *et al*., 2015; Fusari *et al.,* 2018). The present study was intended to determine the visitation rates and population abundance of hoverflies foraging on cucurbit crops to compile data that may contribute to their protection and conservation in Tanzania.

4.3 Materials and methods

4.3.1 Study site

The research was undertaken in Morogoro region Eastern-Central Tanzania, located between S5°58'- S10°0' latitude and between E35°25'- E38°30' longitude (URT, 2002), between March and July 2020. Two different agro-ecological zones (referred to as Plateau and Mountainous) of the Morogoro region were selected to establish a total of six experimental fields as shown in Table 1. Six cucurbit fields of 4047 m^2 size each were established at least 1 km apart in the two different agro-ecological zones. Three cucurbit crop species, cucumber (*Cucumis sativus L.*), watermelon (*Citrullus lanatus Thunb.*) and squash (*Cucurbita moschata* D.) were planted at a spacing of 50 cm x 60 cm, 1 m x 1.5 m and 1 m x 1.5 m, respectively. Each crop was planted in area of 1012 m^2. Distance between fields was at least 1 km.

Table 4.1: Location of six cucurbit fields established in the different agro ecological zones of the Morogoro region from March to July 2020 season.

Location of field plots in two different Agro ecological zones			
Plateau zone	**Coordinates**	**Altitude**	Low altitude area
1. SUA Crop Museum	S06˚51'00.53" E 37˚39'17.90"	528m	
2. SUGECO	S06° 50′ 22” E 37° 38′ 42.2”	511m	
3. SUA Mazimbu	S06˚47'26.208" E 37˚38'7.926"	486m	
Mountainous zone			High altitude area
1. Morning Site	S06° 53′ 17.9” E37° 40′ 14.93”	1274 m	
2. Ruvuma	S06˚52'34.6", E 37˚40'3.7"	995m	

3. Mgola	S06˚52'24.2" E 37˚40'21.5"	1084m

4.3.2 Sampling methods

Sampling of hoverflies visiting cucurbit flowers was carried out following the methodology described by Meerabai (2012) with some modifications. The modifications involved the establishment of three permanent 15 m long transects in each crop plot. A slow walk was done along each transect, counting and recording the identity of every hoverfly seen foraging flowers within 2 m on either side of each transect. Three most abundant hoverfly species were identified and selected for observations after two weeks of preliminary observations. During both the wet and dry season, counts of dominant hoverfly species were performed throughout the flowering periods three times a day (7:30 - 08:30, 11:30 - 12:30 and 15:30 -16:30h). Data were summed to get weekly counts. Data were taken once a week for a period of five weeks in each season.

The floral visitation rate was determined by carrying out observations on individual hoverflies at a close range to a maximum of one minute while they were actively foraging at flowers. Flies were defined as visitors if they probed flowers or contacted reproductive parts. The abundance of hoverflies was determined as the average number of individuals recorded per count. Taxonomic identification of specimens to family level was done at Sokoine University of Agriculture (SUA) Entomology Laboratory using standard keys descried by Kirk-Spriggs and Sinclair 2017; Marshall and Kirk-Spriggs 2017 while identification to species levels was done using keys described by Coe, 1953;Gilbert, 1986; Couri *et al.,* 2012; Ball and Morris, 2015; De Meyer *et al.,* 2020). Representative specimens of each morphospecies were sent to the Royal Museum for Central Africa (RMCA), Tervuren, Belgium for to confirm identifications.

4.3.4 Data collection

For each observation sequence, total time spent on flowers and total observation time which included time in flowers plus time in flight between two consecutive flowers were recorded. Number of flowers visited over the entire observation period was also recorded. Visitation rate was computed as the average number of flower visited per unit time. While the contributions of each fly taxon to total crop visitation rate was estimated as the product of abundance and visitation rate. Weekly abundance of each hoverfly species in each zone were used to determine the abundance of hoverflies.

4.4 Statistical analysis

The data on visitation rate and abundance of dominant Hoverfly species associated with cucurbit crops were organized in excel sheets for computation of average visitation rates and population abundance. The obtained values were subjected to Analysis of Variance (ANOVA) using JMP statistical software (version 14) (SAS Institute Inc., Cary, North Carolina) to highlight the statistical differences in visitation rate and abundance among species between seasons, species, and agro-ecological zones as well as flowering week. Differences in means abundance and visitation rates were determined using Turkey HSD test at 5% level of significance.

4.5 Results

4.5.1 Abundance of hoverfly flies associated with cucurbit crops in the area

In total, 332 Hoverfly specimen were recorded during the observation of flower visitors of cucurbit crops from six established cucurbit fields during March to July 2020. Specimens belonged to eight species: *Eristalinus megacephalus, Paragus borbonicus, Allograpta* sp1, *Eumerus* sp1, *Mesembrius caffer, Phytomia curta, Toxomerus floralis and Syritta fasciata.* Of the total specimens counted, 53.9% were recorded from the mountainous zone and 46.1% from the plateau zone (Appendix 1). The abundance of the three most abundant species were determined in each agroecological zone. Results showed that abundance differed significantly ($P<0.05$) among species and between agroecological zones (Table 4.2). The effects of flowering week and season as well as all interactions among factors were not significant ($P>0.05$).

Table 4. 2: Analysis of variance for the effect of zone, season, flowering stage and species on abundance of dominant species from March to July 2020 season.

Source of variation	d.f.	Sum of Squares	F	**P-value**
Season	1	0.083	2.900	0.0911ns
Agroecological zone	1	0.336	11.732	0.0008*
Species	2	0.654	11.403	0.0001*
Flowering week	4	0.071	0.627	0.6440ns
Season × agroecological zone	1	0.017	0.606	0.4375ns
Season × species	2	0.018	0.323	0.7245ns
Season × flowering week	4	0.028	0.251	0.9086ns
Agroecological zone × species	2	0.082	1.435	0.2420ns
Agroecological zone × flowering week	4	0.012	0.109	0.9789ns
Species × flowering week	8	0.286	1.250	0.2762ns
Season × agroecological zone × species	2	0.058	1.022	0.3629ns
Season × species × flowering week	8	0.097	0.426	0.9033ns
Agroecological zone × species × flowering week	8	0.354	1.543	0.1493ns
Season × agroecological zone × flowering week	4	0.026	0.233	0.9190ns
Season × agroecological zone × species × flowering week	8	0.438	1.912	0.0641ns

* Indicates significant and **ns** indicates not significant

Mesembrius caffer was the most abundant and consistent flower visitor of cucurbit crops across the two agroecological zones and accounted for 30% of the total count in the plateau during the wet season and 37.3% during the dry season. The *E. megacephalus* (27.1%, 26.5%) and *T. floralis* (21.4%, 20.5%) were the second and third most abundant species during the wet and dry season, respectively (Figure 4.1).

Similarly, the same pattern of abundance was observed in all dominant species recorded in the mountainous zone during the wet and dry season. The *Mesembrius caffer* which was the most abundant species accounted for 32.6% of the total count during the wet and 33.3% in dry season. *Eristalinus megacephalus* ranked second 31.4%, 32.1% during wet and dry season respectively. *Toxomerus floralis* was third most abundant species in the mountainous zone and accounted for 16.3% of the total count during wet season and 17.2% during the dry season (Figure 4.2).

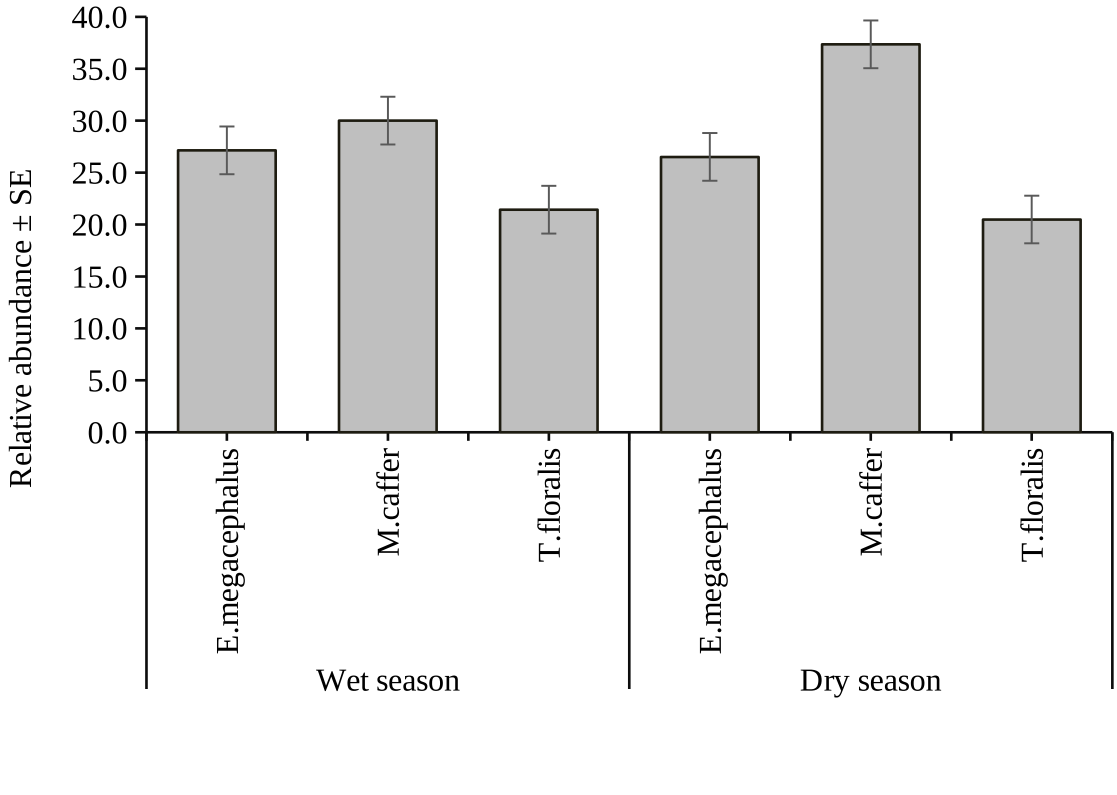

Figure 4.1: Relative abundance ± Standard Error (SE) of syrphid species associated with cucurbit crops in the plateau zone from March to July 2020 season.

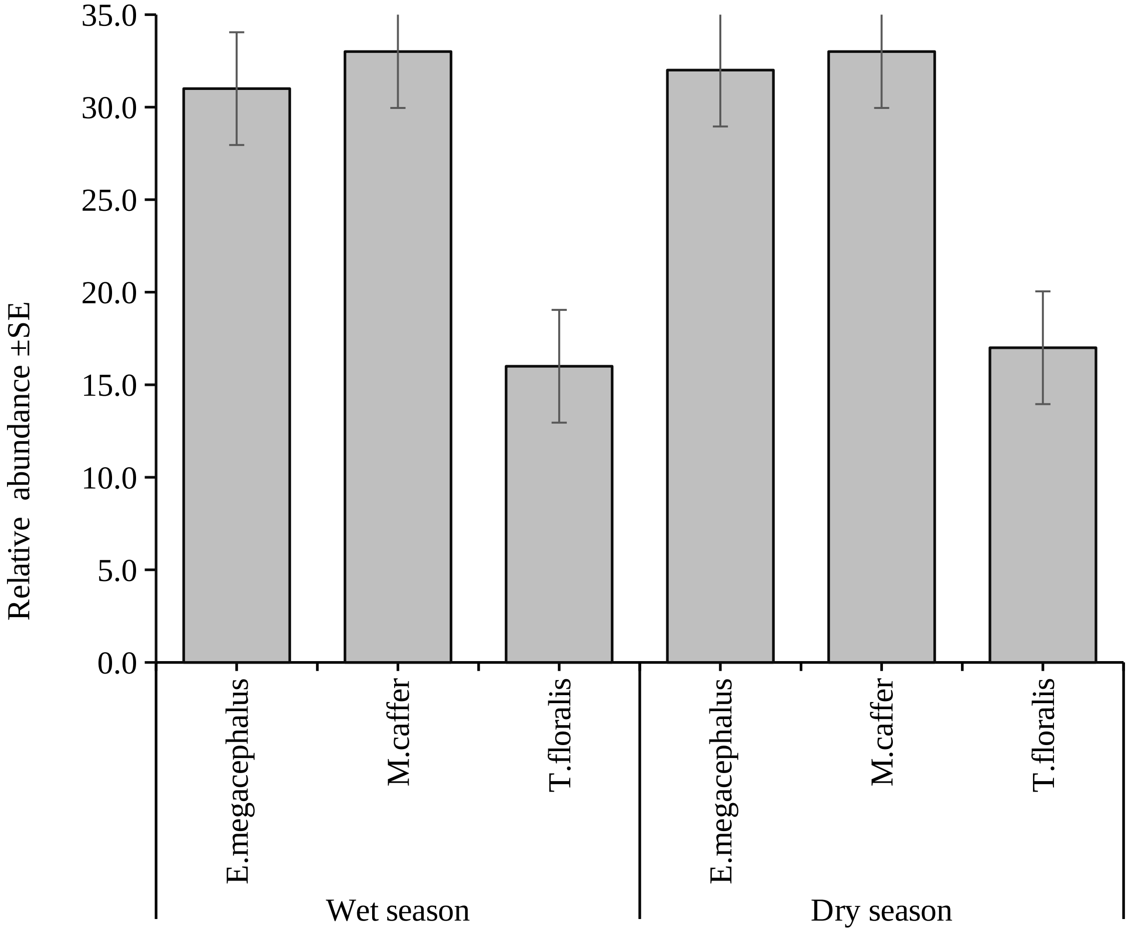

Figure 4.2: Relative abundance ± Standard Error of Syrphid species associated with cucurbit crops in the mountainous zone from March to July 2020 season.

4.5.2 Seasonal visitation rates and contribution of dominant species to the total crop visitation

Visitation rate and contribution of the three most abundant species of hoverfly to the total crop visitation were determined in each agroecological zone (Figure 4.3). The results showed significant variation in visitation rates among species and across the flowering weeks ($P<0.05$). Season, altitude and interaction among all factors did not significantly influence visitation rates ($P>0.05$). *Mesembrius caffer* was the most abundant flower visitor of cucurbit crops in the plateau zone and had the highest visitation rate during the wet and dry season (Figure 4.3). The number of visits contributed by this species was also varied between wet and dry season. However, the *M. caffer* showed a slight low visitation rates in the mountainous zone between the wet and dry season. The number of visits this species offered to the cucurbit flowers during the wet and dry season was also slight low as compared with the number of visits contributed in the plateau zone (Figure 4.3).

Table 4.3: The effect of agroecological zone, season, flowering week and species on visitation rates of dominant species from March to July 2020 season.

Source of variation	d.f.	Sum of Squares	F	P-value
Season	1	0.256	0.772	0.3812ns
Agroecological zone	1	1.216	3.657	0.0581ns
Species	2	8.955	13.456	0.0001*
Flowering week	4	4.405	3.310	0.0129*
Agroecological zone × species	2	0.427	0.641	0.5280ns
Species × flowering week	8	3.324	1.249	0.2761ns
Season × species	2	0.416	0.625	0.5365ns
Agroecological zone × flowering week	4	0.327	0.246	0.9116ns
Season × flowering week	4	0.318	0.239	0.9156ns
Season × agroecological zone	1	0.696	2.094	0.1503ns
Season × agroecological zone × species	2	1.365	2.052	0.1326ns
Season × species × flowering week	8	2.801	1.052	0.4007ns
Season × agroecological zone × flowering week	4	0.487	0.366	0.8322ns
Agroecological zone × species × flowering week	8	1.221	0.459	0.8828ns
Season × Agroecological zone × species × flowering week	8	0.4457	0.726	0.8934ns

* Indicates significant and **ns** indicates not significant

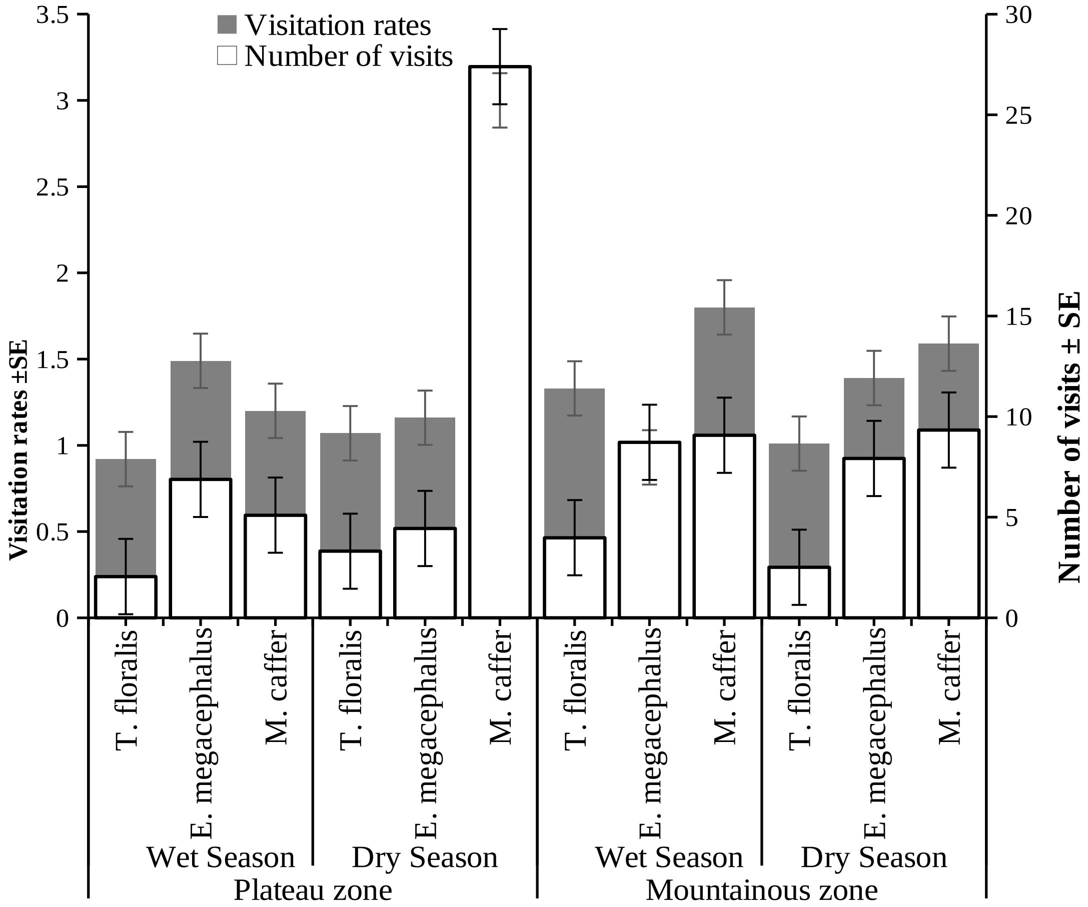

Figure 4. 3: Floral visitation rates and number of visits of dominant hoverfly species associated with cucurbit crops in the plateau zone and mountainous zone in the Morogoro region from March to July 2020 season.

Eristalinus megacephalus ranked second in visitation rates and contributed a substantial number of visits to the total crop visitation in plateau zone during the wet and dry season. Likewise, in mountainous zone the *E. megacephalus* was ranked second in visitation rates that due to considerable high number of visits contributed to the total crops visitation during the wet and dry season (Figure 4.3).

Moreover, the *Toxomerus floralis* ranked third in high visitation rates and in number of visits contributed to the crop total visitation in the plateau zone in all seasons (Figure 4.3), but ranked second in visitation rate and in number of visits during the wet season and third in visitation rate and number of visits contributed during the dry season in the mountainous zone (Figure 4.3).

4.5.3 Variation in foraging and flight time among the dominant hoverfly species associated with cucurbit crops in the study area

The results showed that foraging time among the first three dominant syrphid species associated with cucurbit crops differed significantly across seasons and agroecological zones (Table 4.6). Species, flowering week and interaction among all factors did not significantly influence foraging time. *Toxomerus floralis* recorded the highest foraging and flying time among the species during the dry season in plateau zone compared to *E. megacephalus* and *M. caffer* which spent almost the same foraging and flight time (Figure 4). During the wet season, *T. floralis* and *M. caffer* spent almost equal foraging time but took considerable different flight time (Figure 4.4). *T. floralis* spent more time flying between flowers *M. caffer* spent the lowest flight time. The lowest foraging time during the wet season was observed on *E. megacephalus* which also took short time flying between flowers (Figure 4.4).

A substantial variation in foraging time among the dominant species between seasons was also recorded in the mountainous zone. *E. megacephalus recorded* the highest foraging time and took shorted flying time between flowers while *T. floralis* and *M. caffer* had the lowest foraging and longest flight time during the dry season (Figure 4.5). During the wet season, *T. floralis* had the highest foraging and flight time in the mountainous zone compared to *E. megacephalus* and *M. caffer*. The lowest foraging and flight time was recorded in the mountainous zone during the wet season for the *M. caffer* (Figure 4.5).

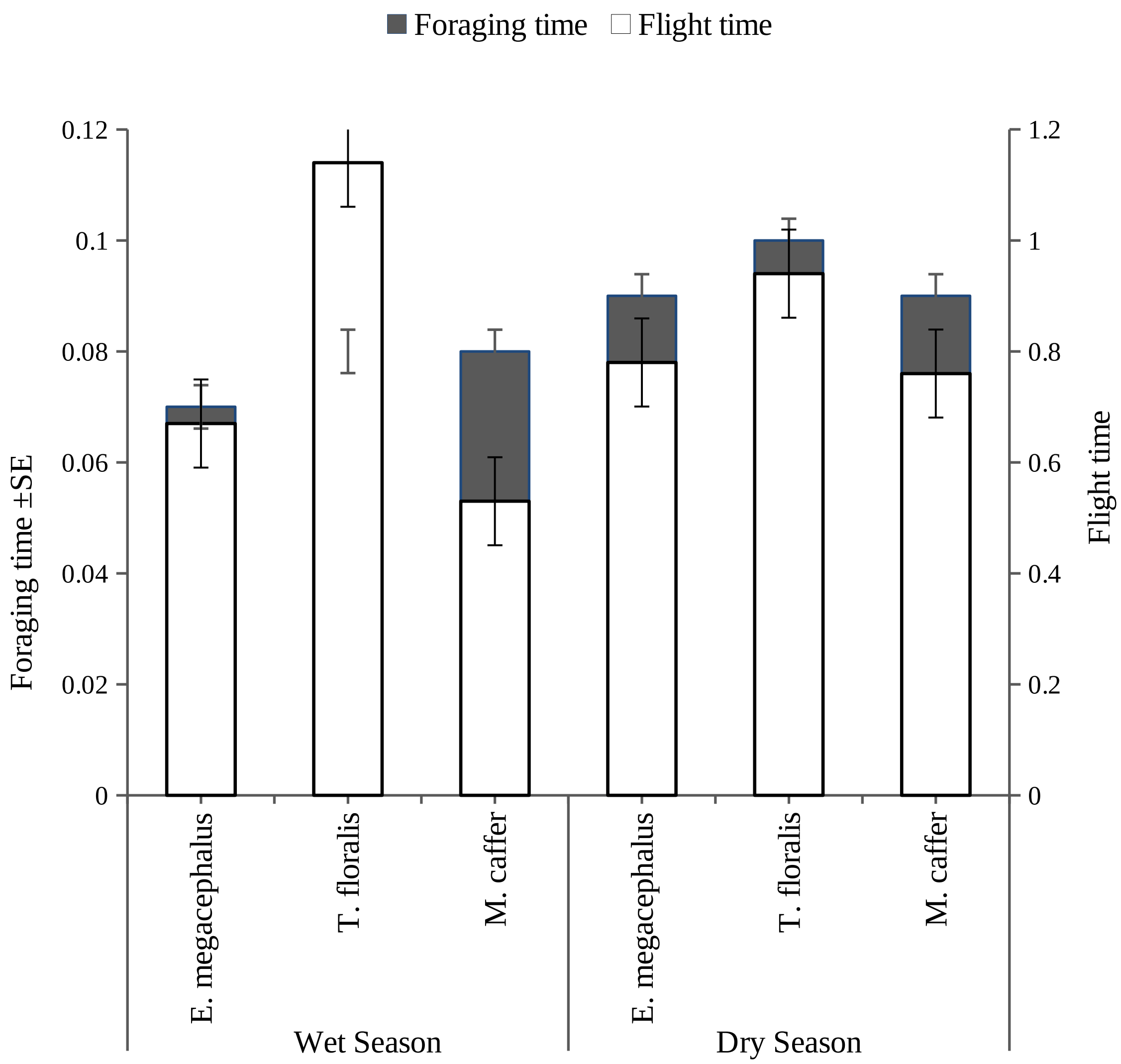

Figure 4.4: Foraging and flight time of dominant hoverfly species associated with cucurbit crops in the plateau of the Morogoro region from March to July 2020 season.

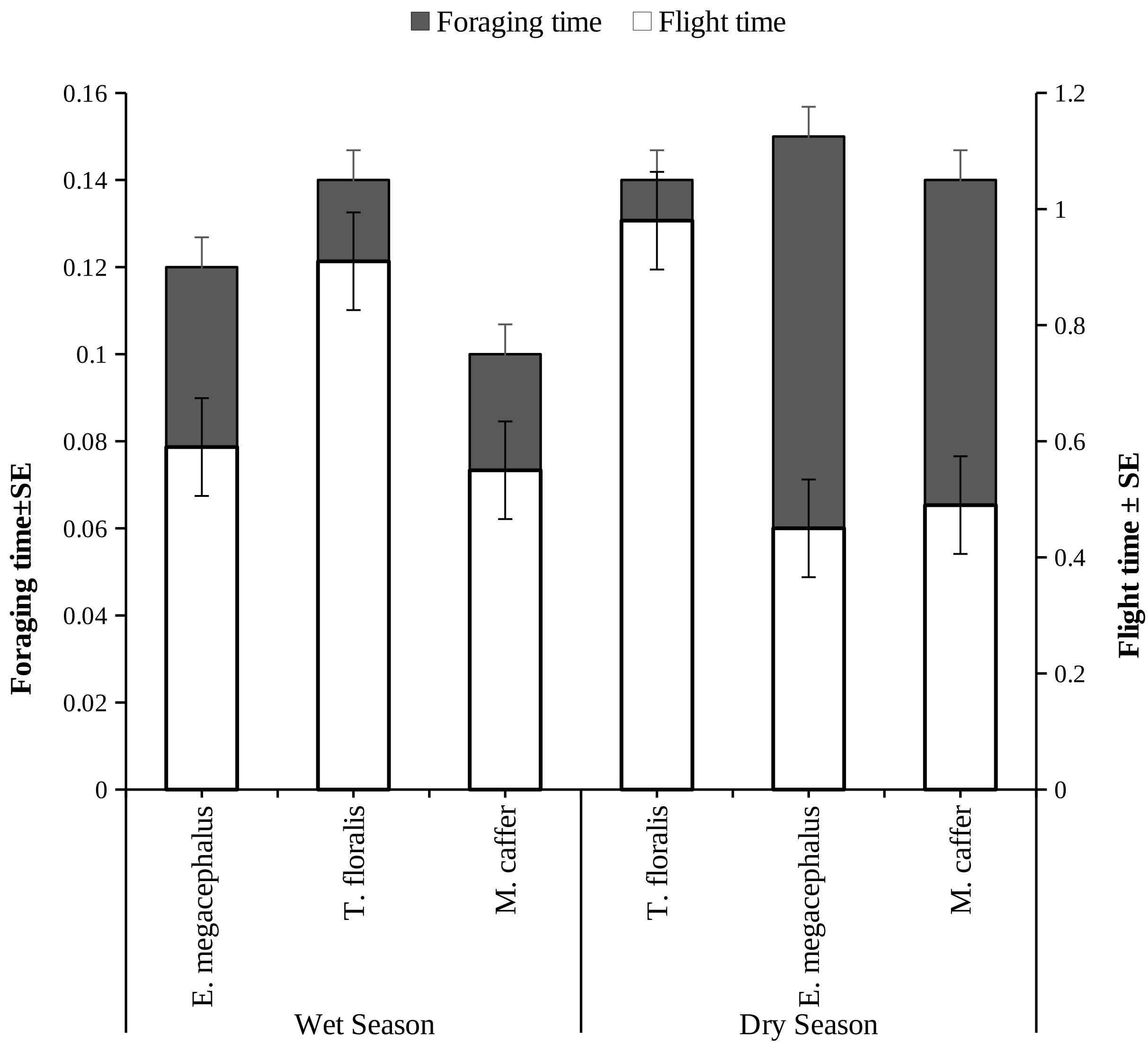

Figure 4.5: Foraging and flight time of dominant hoverfly species associated with cucurbit crops in the mountainous zone of the Morogoro region from March to July 2020 season.

Table 4.6: The effect of agroecological zone, season, flowering week and species on foraging time of dominant species from March to July 2020

Source	d.f.	Sum of Squares	F	P-value
Season	1	0.0607	8.8378	0.0036*
Agroecological zone	1	0.0557	8.1039	0.0052*
Species	2	0.0141	1.0266	0.3614ns
Flowering week	4	0.0104	0.3814	0.8216ns
Season × agroecological zone	1	0.0001	0.0278	0.8679ns
Season × species	2	0.0128	0.9336	0.3960ns
Season × flowering week	4	0.0029	0.1077	0.9796ns
Agroecological zone × species	2	0.0103	0.7493	0.4749ns
Species × flowering week	8	0.0263	0.4786	0.8693ns
Agroecological zone × flowering week	4	0.0170	0.6216	0.6480ns
Season × species × flowering week	8	0.0173	0.3156	0.9588ns
Season × agroecological zone × flowering week	4	0.0184	0.6698	0.6142ns
Season × agroecological zone × species	2	0.0231	1.6858	0.1897ns
Agroecological zone × species × flowering week	8	0.0217	0.3956	0.9211ns
Season × agroecological zone × species × flowering week	8	0.0208	0.3800	0.9295ns

* Indicates significant and **ns** indicates not significant

4.6 Discussion

4.6.1 Abundance of hoverfly species

The results of this study indicate that mountainous zone which is the high altitude area had the highest number of flies/week while the plateau which is low altitude area had the lowest. This is not surprising because most of syrphid fly species including *M. caffer*, *T. floralis* and *E. megacephalus* are known predominantly as low to highland resident (Sengupa *et al.*, 2019). These results suggesting that the high number of syrphid species in the mountainous area were linked to the availability of good microclimate, habitant and abundant food that enhances their longevity and fecundity. The results are in conformity with the findings by Sajjid *et al.* (2010) who found the abundance of hoverflies were related to availability of floral resources. Similar conclusion was also reached by Moquet *et al.* (2018) who reported that the abundance of hoverfly species is linked to high floral density in the ecosystem.

Regarding the abundance of dominant syrphid species, *M. caffer* was the most abundant species in all zones, with *E. megacephalus* and *T. floralis* being less frequent under mountainous zone particularly during the wet season. Variation in abundance among these species across the agroecological zones were coincided with floral resources along the flowering weeks. Similar results have been reported in previous studies on seasonal abundance of hoverflies in low and high altitude area (Sajjid *et al.,* 2010; Martínez *et al.,* 2013; Sengupa *et al.,* 2019) with hoverflies as main pollinators of agricultural crops.

Season and flowering weeks showed no influences on abundance of these dominant species. One of the possible reason could be the species were active foraging flowers between the agroecosystem and nearby vegetation throughout the study period and it was easily for them to fly between the two ecosystems. The other possible reason could be the biology of larvae of hoverflies as they seemed to developing from nearby vegetation and later on forage pollen to the agroecosystem. Furthermore, the species showed a wide range of adaptations for weather conditions and elevational landscapes (Sengupa *et al.,* 2018; De Groot and Vrezec 2019). Similar conclusion was also reached by Mani (2013) who explained the distribution and adaptation of syrphid flies as an alternative pollinators in all agricultural landscape of different altitudinal gradient particularly the higher altitude. It noteworthy that *M. caffer*, *E. megacephalus* and *T. floralis* were the most dominant syrphid species being present even under wet and dry climatic conditions typically of the Morogoro region.

4.6.2 Visitation rates among the dominant hoverfly species in the study area

The present results have showed that the visitation rates of dominant syrphid flies differed substantially among species along the flowering weeks. *Mesembrius caffer*, was the most abundant flower visitors followed by *E. megacephalus* and *T. floralis* was the least frequent flower visitor in all zones and seasons. Many of the previous studies on visitation rates of syrphid flies have also linked such differences in visitation rates with increases in floral density along the flowering periods (Essenberg, 2012; Lazaro *et al.*, 2013 and Totland, 2018). This indicates that as the number of flowers were increasing in the agroecosystem along the flowering weeks, there were also an increase in visitation activities by hoverfly species. These results are also consistent with previous studies that linked the variation in visitation rates among species were due to differences in flight and foraging time attributed by increases in floral resources (Sajjad *et al.,* 2010 and Meerabi, 2012).

The number of flower visits by *M. caffer, E. megacephalus* and *T. florals* increased considerably with increasing floral density along the flowering season. The most logic explanation seems the increase of flowers over the flowering season in the ecosystem. Similar observations were reported by Laurent *et al.* (2015) and Moquet *et al.* (2018) who reported that the abundance and species richness of Hoverfly were increasing with increases in floral density.

Both season and agroecological zone as well as their interactions showed no influence on visitation rates among the hoverfly species. The possible reason could be due to adaptability nature of syrphid flies to a wide range altitude and season. Similar results were also reported by Totland (2018) who explained that season had less impact on the visitation activities of hoverfly species low altitude. A study by Sengupa *et al*. (2019) on abundance hoverfly species as important pollinators in high altitude area was also reported similar results.

We showed that hoverfly species are more active throughout the study period and frequently visit cucurbit flowers. We thus assume that the number of flower visits contributes substantially to the pollination of cucurbit crops and that hoverflies may therefore increase crop yield of these crops.

4.6.3 Variation in foraging and flight time among the dominant hoverfly species

The results have shown here that foraging time among the first three dominant hoverfly species were influenced by season and agroecological zones along the flowering period. Differences in foraging time of these dominant hoverfly species among the agroecological zone was substantial remarkably between seasons. *T. floralis* showed the highest foraging time between wet and dry season, whereas *E. megacephalus* and *M. caffer* had almost similar foraging time during dry season but slightly differed during the wet season. This is indicated that differences among the species was no significant within zone but considerably significant across the two zones between seasons. This could only be due change in weather conditions and number of flowers on a host plant along different landscape characteristics. Similar conclusion was also provided by Souza-Silva *et al.*, (2001) who reported the frequency of flower visits varied among the seasons and is due to flower abundance and climatic conditions. In contrary to the plateau zone, the *T. floralis* had slight the highest foraging time in the mountainous zone during wet season followed by *E. megacephalus* and *M. caffer* while during the dry season both species had almost the same foraging time. This is also suggesting the similar results as in plateau zone.

In both agroecological zones, the differences in foraging time among hoverfly species between seasons could be due to differences in time spent flying between flowers, number of flowers present at a time and the prevailing weather conditions. The results are in accordance with previous findings by Inouye *et al.* (2015) and Babaei *et al.* (2018) who reported that patterns of flower foraging among dipteran flies are constrained by various environmental factors, number of flowers on a host plant and duration of flowering as well as fighting time between flowers. However, species flowering weeks and their interaction did not show any influence on foraging time. This could only explain that foraging activities of these species may not directly be influenced by intrinsic factors of among species but also not with flowering stages at which the insect visits the flowers.

4.7 Conclusion

This study therefore, highlights the most abundant hoverfly species and their contribution toward floral visitation rate, which in facts is a critical activities during insect pollination. The information contained in this study will assist ecologists, entomologists and agriculturalist to efficiency optimize the use of these flies for designing pollinator conservation management and for diversifying the use dipteran flies in agriculture production.

References

Aizen, M. A., Garibaldi, L. A., Cunningham, S. A. and Klein, A. M. (2009). How much does agriculture depend on pollinators? Lessons from long-term trends in crop production. *Annals of Botany* 103(9): 1579 – 1588.

Albano, S., Salvado, E., Borges, P. A. V. and Mexia, A. (2009). Floral visitors their frequency activity rate and Index of Visitation Rate in the strawberry fields of Ribatejo Portugal : Selection of potential pollinators. *Advances in Horticultural Sciences* 23(4): 238 – 245.

Artins, R. O. P. M., Geral, D. D. B. and Federal, U. (2001). Seasonal Abundance and Species Composition of Flower-Visiting Flies. *Neotropical Entomology* 30(3): 351–359.

Babaei, M. R., Asghar Fathi, S. A., Gilasian, E. and Barimani, V. H. (2018). Floral preferences of hoverflies (Diptera: Syrphidae) in response to the abundance and species richness of flowering plants. *Zoology in the Middle East* 64(3): 228 – 237.

Ball, S. and Morris, R. (2015). *Britain's Hoverflies a Field Guide*. 2nd ed. Princeton University Press, Princeton. 312pp.

Bashir, M. A., Saeed, S., Sajjad, A., Khan, K. A., Ghramh, H. A., Shehzad, M. A., Mubarak, H., Mirza, N., Mahpara, S., Rehmani, M. I. A. and Ansari, M. J. (2019). Insect pollinator diversity in four forested ecosystems of southern Punjab, Pakistan. *Saudi Journal of Biological Sciences* 26(7): 1835–1842.

Bomfim, I., Freitas, B., de Aragão, F. and Walters, S. (2016). Pollination in cucurbit crops. In *Handbook of Cucurbits: Growth, Cultural Practices, and Physiology*. CRC Press, Do Sertão. 200pp.

Chen, M. and Zuo, X. A. (2019). Effect of pollen limitation and pollinator visitation on pollination success of Haloxylon ammodendron (CA Mey.) bunge in fragmented habitats. *Frontiers in Plant Science* 10(327): 1 – 12.

Classen, A., Eardley, C. D., Hemp, A., Peters, M. K., Peters, R. S., Ssymank, A. and Steffan-Dewenter, I. (2020). Specialization of plant–pollinator interactions increases with temperature at Mt. Kilimanjaro. *Ecology and Evolution* 11: 2182 – 2195.

Coe, R.L. (1953). Diptera – Syrphidae. In Handbooks for the identification of British insects. London, Royal International Entomological Society of London 10 (1): 1-98

Couri, M. S., De Carvalho, C. J., and Pont, A. C. (2012). Taxonomy of the Muscidae (Diptera) of Namibia: a key to genera, diagnoses, new records and description of a new species. *African Invertebrates*, 53(1): 47-67.

De Groot, M. and Vrezec, A. (2019). Contrasting effects of altitude on species groups with different traits in a non-fragmented montane temperate forest. *Nature Conservation* 37: 99 – 121.

De Meyer, M. A. R. C., Goergen, G. and Jordaens, K. (2020). Taxonomic revision of the Afrotropical Phytomia Guérin-Méneville (Diptera: Syrphidae). *Zootaxa* 4803(2): 201 – 250.

Ebeling, A., Klein, A. M., Schumacher, J., Weisser, W. W. and Tscharntke, T. (2008). How does plant richness affect pollinator richness and temporal stability of flower visits? *Oikos* 117(12): 1808 – 1815.

Essenberg, C. J. (2012). Explaining variation in the effect of floral density on pollinator visitation. *The American Naturalist* 180(2): 153 – 166.

Fusari, L. M., Dantas, G. P. S. and Pinho, L. C. (2018). Order Diptera. Keys to neotropical hexapoda in thorp and covich’s freshwater invertebrates. *Science Direct* 3: 607 – 623.

Gervais, A., Chagnon, M., and Fournier, V. (2018). Diversity and pollen loads of flower flies (Diptera : Syrphidae) in Cranberry Crops. *Annals of the Entomological Society of America* 8: 1 – 9.

Gilbert, F.S. (1986). Hoverflies. Naturalists' handbook 5. Cambridge, Press Syndicate of the University of Cambridge, 64 p.

Inouye, D. W., Larson, B. M., Ssymank, A. and Kevan, P. G. (2015). Flies and flowers ecology of foraging and pollination. *Journal of Pollination Ecology* 16(16): 115 – 133.

Johansson, V., Gustafsson, L., Andersson, P. and Hylander, K. (2020). Fewer butterflies and a different composition of bees, wasps and hoverflies on recently burned compared to unburned clear-cuts, regardless of burn severity. *Forest Ecology and Management* 463(118033): 1 – 15.

Klein, A. M., Vaissière, B. E., Cane, J. H., Steffan-Dewenter, I., Cunningham, S. A., Kremen, C. and Tscharntke, T. (2007). Importance of pollinators in changing landscapes for world crops. Proceedings of the Royal Society: *Biological Sciences* 274(1608): 303 – 313.

Lautenbach, S., Seppelt, R., Liebscher, J. and Dormann, C. F. (2012). Spatial and temporal trends of global pollination benefit. *PLoS One* 7(4): 35 – 954.

Lázaro, A., Jakobsson, A. and Totland, Ø. (2013). How do pollinator visitation rate and seed set relate to species' floral traits and community context? *Oecologia* 173(3): 881 – 893.

Mani, M. S. (2013). *Ecology and Biogeography of High Altitude Insects*. Springer Science and Business Media, Northlands. 179pp.

Martínez-UñA, A., MartÍn, J. M., Fernández-Quintanilla, C. and Dorado, J. (2013). Provisioning Floral Resources to Attract Aphidophagous Hoverflies

(Diptera: Syrphidae) Useful for Pest Management in Central Spain. *Journal of Economic Entomology* 106(6): 2327 – 2335.

Meerabai, G. (2012). Visitation rate, effectiveness and efficiency of pollinators to Cadaba fruiticosa (Linn) Druce. *The Bioscan* 7(3): 483 – 485.

Moquet, L., Laurent, E., Bacchetta, R. and Jacquemart, A. L. (2018). Conservation of hoverflies (Diptera, Syrphidae) requires complementary resources at the landscape and local scales. *Insect Conservation and Diversity* 11(1): 72 – 87.

Orford, K. A., Vaughan, I. P. and Memmott, J. (2015). The forgotten flies : The importance of non-syrphid Diptera as pollinators. *Proceedings of the Royal Society Biological Sciences* 282(1805): 2014 – 2934.

Primack, R. B. and Inouye, D. W. (1993). Factors affecting pollinator visitation rates: A biogeographic comparison. *Current science* 65(1): 257 – 262.

Sajjad, A. and Saeed, S. H. A. F. Q. A. T. (2010). Floral host plant range of syrphid flies (Syrphidae: Diptera) under natural conditions in southern Punjab, Pakistan. *Pakistan Journal of Botany* 42(2): 1187 – 1200.

Sajjad, A., Saeed, S. and Ashfaq, M. (2010). Seasonal variation in abundance and composition of hoverfly (Diptera: Syrphidae) communities in Multan, Pakistan. *Pakistan Journal of Zoology* 42(2): 105 – 115.

Sawe, T., Eldegard, K., Totland, Ø., Macrice, S., and Nielsen, A. (2020). Enhancing pollination is more effective than increased conventional agriculture inputs for improving watermelon yields. *Ecology and Evolution* 10(12): 5343 – 5353.

Sawe, T., Nielsen, A., Totland, Ø., Macrice, S. and Eldegard, K. (2020). Inadequate pollination services limit watermelon yields in northern Tanzania. *Basic and Applied Ecology* 44: 35 – 45.

Sengupta, J., Naskar, A., Homechaudhuri, S. and Banerjee, D. (2019). Diversity of Hover flies (Insecta: Diptera: Syrphidae) with 3 New Record from High Hill Zone of

Himachal Pradesh, India. In*ternational Journal of Advancement in Life Sciences Research* 4: 21 – 37.

Sengupta, J., Naskar, A., Maity, A., Homechaudhuri, S. and Banerjee, D. (2018). Distributional scenario of hover flies (Diptera: Syrphidae) from the state of West Bengal. *Munis Entomology Zoology* 13: 447 – 457.

Souza-Silva, M., Fontenelle, J. C. and Martins, R. P. (2001). Seasonal abundance and species composition of flower-visiting flies. *Neotropical Entomology* 30(3): 351 – 359.

Ssymank, A., Kearns, C. A., Pape, T. and Thompson, F. C. (2008). Pollinating flies (Diptera): a major contribution to plant diversity and agricultural production. *Biodiversity* 9(2): 86 – 89.

Totland, Ø. (1994). Influence of climate, time of day and season, and flower density on insect flower visitation in alpine Norway. *Arctic and Alpine Research* 26(1): 66 – 71.

United Republic of Tanzania (2002). *Morogoro Regional Socio-Economic Profile*. Morogoro Regional Commissioner’s Office, Morogoro. 229pp.

CHAPTER FIVE

5.0 Spatial and Temporal Abundance of Flower Visiting Flies Associated with Cultivated Cucurbit Crops in Morogoro, Eastern-Central Tanzania

S.A. Kabota[1*], **M. W. Mwatawala**[1], **M De. Meyer**[2] and **K. Jordaens**[2]

[1]Department of Crop Science and Horticulture, Sokoine University of Agriculture (SUA), P.O. Box 3005 Chuo Kikuu, Morogoro, Tanzania,

[2]Royal Museum for Central Africa, Invertebrates Section and JEMU, Leuvensesteenweg 13, B3080 Tervuren Belgium.

Corresponding author, e-mail: sijakabota@gmail.com

To be submitted to the Journal of Insect Conservation and Diversity (Willey)

5.1 Abstract

Cucurbit crops are among major food crops that rely largely on insect pollination to set fruits and seeds. Their flowers offer large quantity of nectar and pollen as floral rewards to visiting insects. However, little studies have been done to investigate the spatial and temporal abundance of flower visiting flies associated with cultivated cucurbit crops in Tanzania. Therefore, this study investigated the seasonal abundance of flower visiting flies associated with three cultivated cucurbit crops (*Cucumis sativus L., Citrullus lanatus Thunb*. and *Cucurbita moschata D.*) using yellow pan traps and hand netting in ten established cucurbit fields along mountainous and plateau zones of the Morogoro region. Trapping of flower visiting flies commenced when crops are at least at 10% flowering stage from March to July 2020. A total of 7606 individuals were collected, of which 396 specimens belonged to eight (8) genera and nine (9) species of Syrphidae (Hoverflies). Of the total hoverfly species recorded, *Eumerus* (Meigen) sp1 was the most abundant and predominate species followed by *Eristalinus megacephalus* (Rondani) and *Toxomerus floralis* (Macquart) in the study area. The abundance of hoverfly species were influenced by agroecological zones and weather conditions which linked to variability of floral resources. The population abundance of dominant Hoverfly species varied among species

across the two agroecological zones. Therefore, this work suggests that spatial and temporal abundance of hoverflies is dynamic on a micro-geographic scale as it seems to be mostly influenced by zones and species themselves.

Key words; Spatial and temporal abundance, flower visiting flies, Hoverfly, Cucurbit crops.

5.2 Introduction

Flower visiting flies constitute one of the most economically important group of flower visitors and pollinators of flowering plants (Totland, 1994; Marshall and Kirk-Spriggs, 2017). Adults of many families of dipteran flies regularly visit flowers to obtain food in the form of nectar and pollen to fuel their metabolically costly flights (Bashir *et al.*, 2018; Marshall and Kirk-Spriggs, 2017; Courtney *et al.*, 2009; Latif *et al.,* 2019). In some cases these flies visit flowers in search for hosts, shelter and mating rendezvous sites (Marshall and Kirk-Spriggs, 2017; Larson *et al.*, 2001). The most common flower visiting flies include members from families Bombyliidae, Syrphidae, Calliphoridae and Muscidae but also many other members from thirty families, mostly Brachycera are also involved in pollination service (Marshall and Kirk-Spriggs 2017; Kearns, 2001; Ssymank *et al.*, 2007). Flower visiting flies are widely distributed and have successfully colonized every continent (Marshall and Kirk-Spriggs, 2017; Larson *et al.*, 2001; Ssymank *et al.*, 2007), and a considerable number of these flies have been reported in the Afrotropical region (Marshall and Kirk-Spriggs, 2017; Kirk-Spriggs and Sinclair, 2017).

About 86 families of Diptera comprises flower visiting flies, of which 31 families are known to occur in the Afrotropical countries including Tanzania (Marshall and Kirk-Spriggs, 2017). In the region, these flies are pollinators to a wide range of economically important crops such as mango, cashew, tea, cacao, onion, strawberry, cauliflower, mustard, carrot, apple, leek, cassava, and pepper (Aizen *et al.*, 2009; Garibaldi *et al.*, 2013; Klein *et al.*, 2007). However, data on their use as pollinators are very limited in Tanzania (Classen *et al.,* 2015; Sawe *et al.*, 2020). The abundance and distribution of these flies depend on availability of key resources, climatic condition and suitable habitants (Artins *et al.,* 2001; Habel and Ulrich, 2020; Sengupta *et al.,* 2016; Totland, 1994). Such factors directly influence the spatial and temporal dynamics of flower visiting flies in the ecosystems (Artins *et al.,* 2001; Baldacchino *et al.,* 2014). In most cases, the population of flower visiting flies vary seasonally, but the extent of variation differs with altitudes, seasons and climatic conditions (Artins *et al.,* 2001).

In Tanzania, the biodiversity of flower visiting flies has been inadequately studied, thus many species remain unknown. This is because the abundance and distribution patterns of flower visiting flies has not been the subject of much study in the past. Most previous studies were concentrated on bees and fruit flies (Classen *et al.,* 2015; Mwatawala *et al.,* 2006; Mziray *et al.,* 2010) while the abundance and distribution of flower visiting flies has remained undocumented.

Thus, determining the spatial and temporal abundance of flower visiting flies is of great importance, as it provides valuable information about their population dynamics and dispersal ecology. Knowledge regarding spatial and temporal abundance of flower visiting flies is therefore necessary for developing effective and sustainable pollinator conservation strategies.

5.3 Materials and Methods

5.3.1 Study site

Studies were conducted in two agro-ecological zones (the plateau zone and mountainous zone) of the Morogoro region, Eastern-Central Tanzania. The plateau zone is located between 300–600 m above the sea level with average rainfall ranging between 700 mm–1200 mm per annum while the mountainous zones is located above 600 m above the sea level with average rainfall ranging from 800 mm up to 2500 mm per annum (Anon, 2002). The Morogoro region is located in the transition zone between the bimodal and unimodal rainfall belts at S5°58'- S10°0'South and E35°25'- E38°30' East (URT, 2002). Pollinating flies were collected from March to July 2020 from ten established cucurbit fields as indicated in the (Table 1) below.

Table 5.1: Locations of experimental field plots in the Morogoro region

Location of field plots in two different Agro ecological zones			
Plateau zone	**Coordinates**	**Altitudes**	
1. SUA Horticulture Unit	S06˚50'41.4" E 37˚39'43.3"	524 m	Low altitude area
2. SUA Crop Museum	S06˚51'00.53" E 37˚39'17.90"	528 m	
3. SUGECO	S06° 50′ 22" E 37° 38′ 42.2"	511 m	
4. SUA Mazimbu	S06˚47'26.208" E 37˚38'7.926"	486 m	
5. SUA Mafiga	S06˚50'22.764" E 37˚37'53.46"	503 m	
Mountainous zone			High altitude area
1. Morning Site	S06° 53′ 17.9" E37° 40′ 14.93"	1274 m	
2. Mkumbulu	S06˚52'24.2" E 37˚40'21.5"	1105 m	
3. Ruvuma	S06˚52'34.6", E 37˚40'3.7"	995 m	
4. Kifuru	S06˚53'32.1" E 37˚40'9.5"	1418 m	
5. Mgola	S06˚51'41.4" : E 37˚40'4.3"	1084 m	

5.3.2 Sampling method

The seasonal abundance of flower visiting flies associated with cucurbit crops were monitored using yellow pan traps and hand netting from the month of March to July 2020. Five plots of 4047m^2 in size each were established from each agro-ecological zones (mountainous and plateau zone) of the Morogoro region. Distance between the fields was approximately 1 km. In each field, three cucurbit crop species, cucumber (*Cucumis sativus*), watermelon (*Citrullus lanatus*) and squash (*Cucurbita moschata*) were planted at a spacing of 50 cm x 60 cm, 1 m x 1.5 m and 1 m x 1.5 m. Each crop occupied a sub plot of 1012m^2.

Samplings of flower visiting flies commenced when the crops were at 10% flowering stage and continued throughout the flowering period following the methodology described Mokam *et al.* (2014). A total of 16 yellow pan traps containing deterged water to about three quarter of their volume were uniformly distributed in each field. The pan traps were baited at two days interval and then emptied by sieving and picking the trapped flies using fine sieving net and forceps. A 30 cm wide entomological hand nets were used to collect flower visiting flies attending flowers when flowers were fully open and functional along 5 m transects. The collected flies were stored in the plastic vials containing 70% alcohol prior and after sorting. Flies that were collected three times a week constituted a weekly catch. Taxonomic identification of specimens was done at Sokoine University of Agriculture (SUA) Entomology Laboratory. Determination of specimen to family level was done using standard keys described by Kirk-Spriggs and Sinclair, 2017 and Marshall and Kirk-Spriggs 2017 while determination of specimen to species levels was done using keys described by Coe, 1953; Gilbert, 1986; Tschorsnig and Herting, 2001; Couri *et al.,* 2012;Whitworth, 2014; Ball and Morris, 2015;Willcox *et al.,* 2019; Thomson, 2019; De Meyer *et al.,* 2020). Samples of specimens were also sent to the Royal Museum for Central Africa (RMCA), Tervuren, Belgium for further identification and confirmation.

5.3.3 Data collection

A weekly fly catch per crop species at each field were counted and recorded and then organized using Microsoft excel sheet, indicating the number of flies species caught per crop species for a given agro-ecological zone.

5.3.4 Statistical analysis

Analysis of variance (ANOVA) were analyzed data using JMP statistical software (version 14) statistical software (SAS Institute Inc., Cary, North Carolina). The factors were season, agroecological zone (altitude), flowering week and species. Post hoc Tukey test was used to compare means.

5.4 Results

5.4.1 Abundance of flower visiting flies associated with cucurbit crops

In total, 7606 specimens were collected from ten (10) established cucurbit fields during the entire study period across plateau and mountainous zones of the Morogoro region. About 77.58% of the total individuals were collected at the Mountainous zone while 22.42% were collected from the plateau zone. The Mkumbulu field recorded the highest number (21.6%) of individuals at the mountainous zone while Kifulu recorded the lowest number (8.7%). In the plateau zone, the highest number of individuals was recorded at the Horticulture unit (5.2%) while the lowest number of individuals was recorded at Mafiga field (3.2%) (Table 5.2). Seven families of pollinating flies were identified from a set of specimen collected during the study period. These included the family Muscidae, Sarcophagidae, Calliphoridae, Syrphidae, Agromyzidae and Tachinidae as well as Simuliidae.

Species from Muscidae family were numerically abundant in all fields for the plateau zone which accounted for more than 68.74% of the total individuals collected in the plateau zone followed by Syrphidae (15.94%), Calliphoridae (6.7%), Sarcophagidae (6.1%), Tachinidae (1.03%), Agromyzidae (1.02%) and Simuliidae (1.014%) (Figure 5.1).

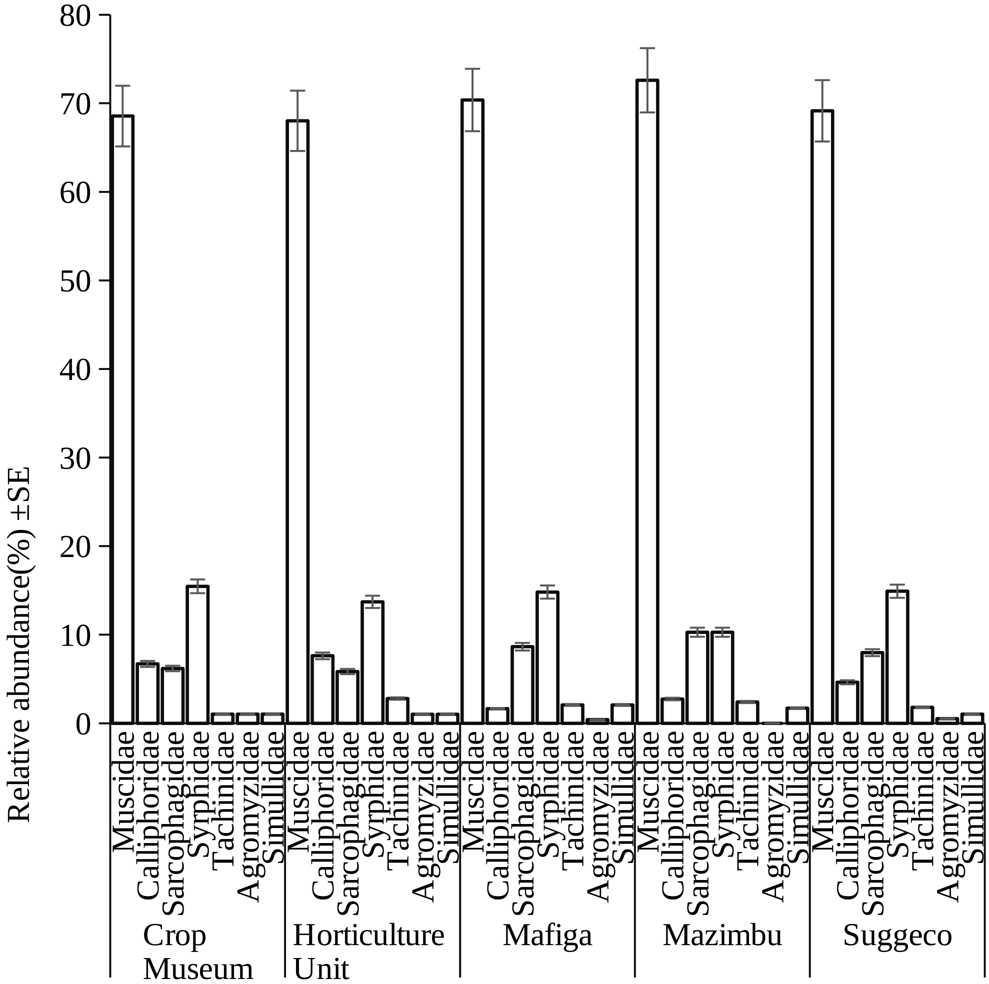

Figure 5.1: Flower visiting flies' families associated with cucurbit crops in the plateau zone of the Morogoro region from March to July 2020 season.

Likewise, in the mountainous zone, species from Muscidae family were the most abundant in all fields which accounted for more 57.59% of the total individuals collected followed by Sarcophagidae (20%), Calliphoridae (13.68%), Syrphidae (3.94%), Agromyzidae (1.56%), Tachinidae (1.2%), and Simuliidae (0.75%) (Figure 5.2).

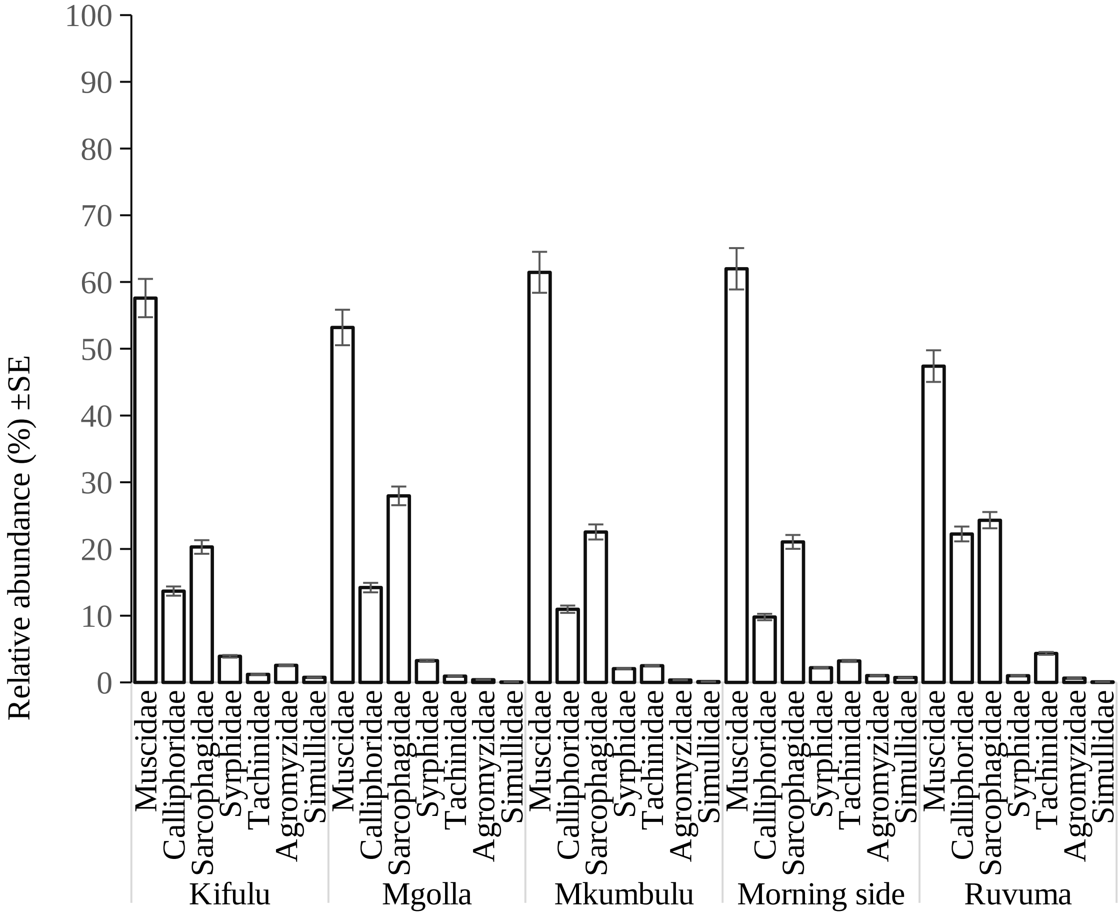

Figure 5.2: Flower visiting flies' families associated with cucurbit crops in the mountainous zone of the Morogoro region from March to July 2020 season.

Some species of flower visiting flies found in cucurbit plots were not necessarily mean they were pollinators, even if they belong to a family that is considered as an important pollinator. The high abundances of Muscidae and others were not considered and their relative pollination efficiency were not discussed. For the sake of brevity and clarity as well as pollination efficiency among these families is considered, only Syrphidae family was considered for further analysis and discussion. This is because Hoverflies are the second most important group of pollinators after wild bees.

Table 5.2: Numbers of different flower visiting flies associated with cucurbit crops in the Morogoro region

Pollinators/Fields	CM	HT	MF	MZ	SUG	KF	MG	MK	MS	RU	Total	%
Lucilia sericata	13	5	3	1	12	18	50	36	14	56	208	2.73
Chrysomya sp1	2	9	1	5	5	21	71	76	26	140	356	4.68
Lucilia cuprina	0	0	0	0	0	7	1	3	6	0	17	0.22
Calliphora vicina	11	5	0	2	1	43	88	51	17	109	327	4.30
Neomyia viridescens	9	1	1	4	1	18	57	35	14	41	181	2.38
Stomoxys calcitrans	19	45	24	16	41	94	231	232	113	166	981	12.90
Musca domestica	234	220	146	192	226	258	496	716	290	450	3228	42.44
Graphomyia sp1	4	2	0	0	1	13	17	26	7	8	78	1.03
Tachina sp1	0	6	0	0	0	2	4	14	4	8	38	0.50
Strongyloneoura sp1	4	5	5	7	7	8	14	41	22	61	174	2.29
Sarcophaga sp1	24	23	21	30	31	135	421	370	144	341	1540	20.25
Eristalinus megacephalus	9	12	7	5	7	6	7	9	5	4	71	0.93
Syritta flaviventris	6	3	4	3	3	6	1	6	1	3	36	0.47
Paragus borbonicus	3	8	2	0	4	5	3	2	1	3	31	0.41
Syritta fasciata	1	3	0	1	0	0	0	0	2	0	7	0.09
Phytomia curta	0	4	0	0	1	1	1	4	1	0	12	0.16
Toxomerus floralis	18	9	11	7	9	2	4	2	1	3	66	0.87
Allograpta sp1	0	3	0	0	1	0	0	0	0	0	4	0.05
Mesembrius caffer	4	12	7	9	4	0	2	3	1	0	42	0.55
Eumerus sp1	19	10	5	5	29	6	31	8	3	1	117	1.54
Agromyzid sp1	4	4	1	0	2	17	6	6	7	9	56	0.74
Simuliid sp1	4	4	5	5	4	5	1	2	5	1	36	0.47
Total	**388**	**393**	**243**	**292**	**389**	**665**	**1506**	**1642**	**684**	**1404**	**7606**	**100**
Percentages	**5.1**	**5.2**	**3.2**	**3.8**	**5.1**	**8.7**	**19.8**	**21.6**	**9.0**	**18.5**	**100**	
			22.42%					**77.58%**				
Total of species	**18**	**21**	**15**	**15**	**19**	**19**	**20**	**20**	**21**	**17**	**22**	

CM; Crop Museum, HT; Horticulture Unit, MF; Mafiga, MZ; Mazimbu , SUG; Sugeco, KF; Kifulu, MG; Mgola, MK; Mkumbulu, MS; Morning side, RU; Ruvuma

Table 5.3: Abundance of hoverfly species recorded in the plateau and mountainous zone of the Morogoro region from March to July 2020 season

Species	Plateau zone		Mountainous zone	
	Abundance	Relative abundance%	Abundance	Relative abundance %
Eristalinus megacephalus	32	22.22	41	16.27
Syritta flaviventris	17	11.81	21	8.33
Paragus borbonicus	13	9.03	16	6.35
Syritta fasciata	4	2.78	5	1.98
Phytomia curta	8	5.56	3	1.19
Toxomerus floralis	18	12.50	53	21.03
Allograpta sp1	0	0.00	4	1.59
Mesembrius caffer	12	8.33	34	13.49
Eumerus sp1	40	27.78	75	29.76
Total	**144**	**100.00**	**252**	**100.00**

5.4.2 Abundance of hoverfly species associated with cucurbit crops in the study area

About 396 Syrphid flies belonging to eight genera and nine species were collected from the plateau and mountainous zone of the Morogoro region and identified during the entire study period (Table 5.3). Of these species, *Eumerus* sp1(Meigen) was the most abundant and predominant species across the two agroecological zones and accounted for of the total 27.76% Syrphid species collected in the plateau, 29.76% in the mountainous zone. The *Eristalinus megacephalus* (Rondani) (22.22%) ranked second in mountainous zone and third (16.75%) in the plateau zone. *Toxomerus floralis* Macquart (21%) ranked second in the plateau zone and third (12.5%) in the mountainous zone. The other remaining species *Mesembrius caffer* (Rondani), *Paragus borbonicus* Latreille, *Phytomia curta* (Loew), *Syritta Fasciata* LePeletier and Serville, *Syritta flaviventris* LePeletier and Serville, and *Allograpta* sp1 Osten sacken were relative low in abundance in all cucurbit fields across the plateau and Mountainous zone.

5.4.3 Seasonal fluctuation and abundance of dominant Hoverfly species associated with cucurbit crops

The first three dominant Hoverfly species were further examined. The results showed that abundance of the dominant species fluctuated significantly among species and between agroecological zones ($P<0.05$) (Table 5.4). The effects of interaction between season and agroecological zone, season and species as well as season, agroecological zone and species were also significant ($P<0.05$). However, the other remaining interactions showed no significant effects on abundance of the first three dominant species under study (P.0.05).

Eumerus sp1 dominated the plateau zone throughout the flowering period and peaked five times from March to July (Figure 5.2). Its abundance increased from 9th March to 06th April which coincided with peak flowering period during the wet season. Two population peaks were observed in the wet season (23rd March and 06th April) with the 23rd March being its highest population peak, while the during the dry season *Eumerus* sp1 peaked on 19th June and 1th July with its highest peak on 19th June which also coincided with peak flowering period (Figure 5.2).

E. megacephalus and *T. floralis* showed only one population peak (23rd March) and their population increased from 9th to 23rd March for the wet season. During the dry season, the *T. floralis* had one population peak on 01st July while the *E. megacephalus* had also one population peak but on 13rd July. Their abundance increased from 25th June to 13rd July during the dry season (Figure 2). Likewise, in the mountainous zone, *Eumerus* sp1 was also the most abundant and predominant species which showed four seasonal population peaks from June to July (Figure 3). Its abundance increased from 16th March to 13rd April and peaked twice (30th March and 13rd April) for the wet season and (19th June and 7th

July) in dry season (Figure 3). Both *T. floralis* and *E. megacephalus* were considerably low in abundance and peaked twice during the wet season (9th and 30th March) and once during the dry season (19th June) (Figure 5.3).

Generally, seasons and agroecological zones observed to be an important determinant factors for seasonal variation in abundance of Syrphid flies in the agroecosystems. Both species varied seasonally and high population abundance coincided with the peak flowering period.

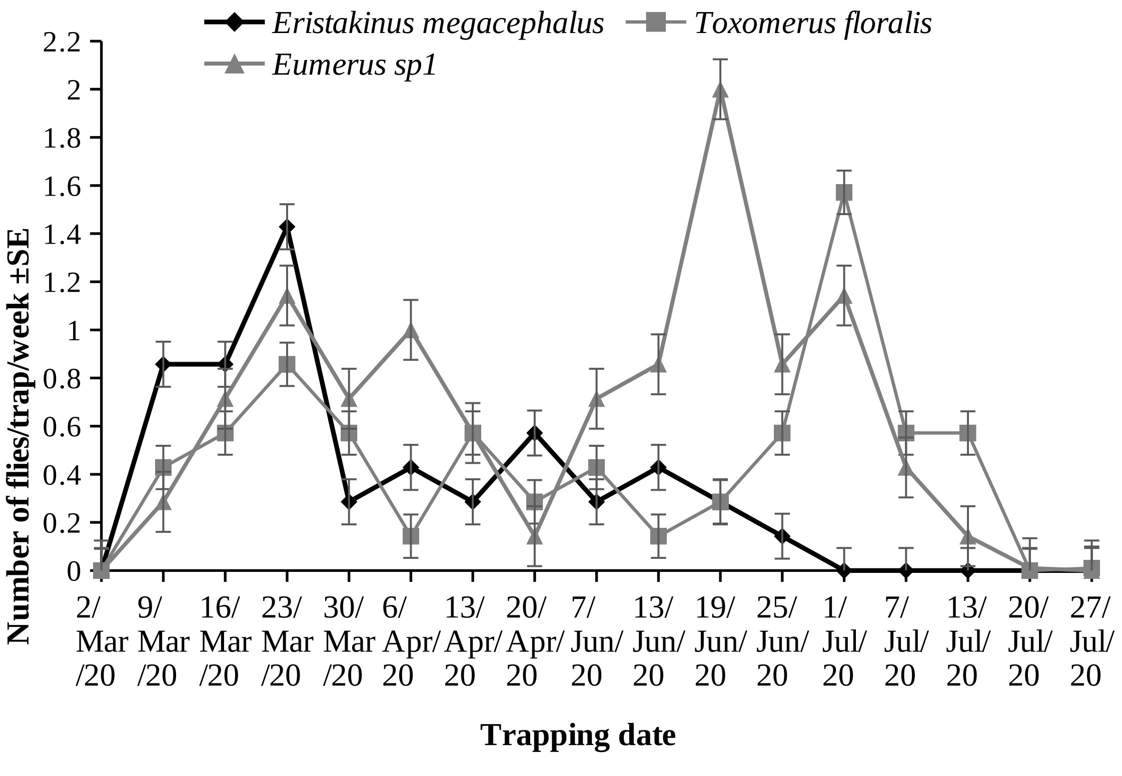

Figure 5.3: Seasonal fluctuation (mean abundance ±SE) of dominant hoverfly species in the plateau zone of the Morogoro region from March to July 2020. March-April corresponds to the wet season and June-July correspond to the dry season.

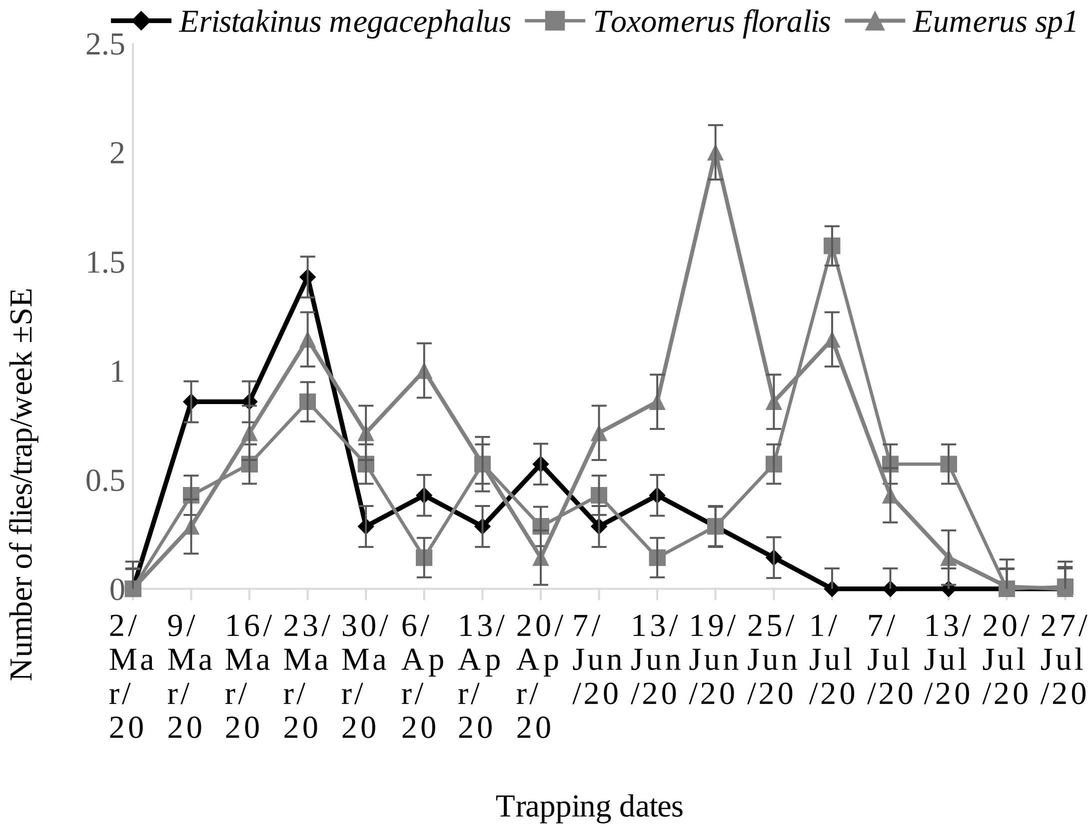

Figure 5.4: Seasonal fluctuation (mean abundance ±SE) of dominant Hoverfly species in the mountainous zone of the Morogoro region during the trapping period from March to July 2020. March-April corresponds to the wet season and June-July correspond to the dry season.

Table 5.4: The effect of Agro-ecological zone, season, flowering week and species on abundance of dominant hoverfly species from March to July 2020 season

Source of variation	d.f.	Sum of Squares	F	P-value
Season	1	0.00003	0.2890	0.5913ns
Agroecological zone	2	0.00192	8.4310	0.0003*
Species	2	0.00146	6.3956	0.0019*
Flowering week	6	0.00109	1.5978	0.1475ns
Season × agroecological zone	2	0.00135	5.9466	0.0029*
Season × species	2	0.00155	6.8236	0.0013*
Season × flowering week	6	0.00067	0.9784	0.4400ns
Agroecological zone × species	4	0.00109	2.3967	0.0505ns
Agroecological zone × flowering week	12	0.00128	0.9338	0.5133ns
Species × flowering week	12	0.00153	1.1222	0.3414ns
Season × agroecological zone × species	4	0.00162	3.5552	0.0075*
Agroecological zone × species × flowering week	24	0.00305	1.1157	0.3248ns
Season × species × flowering week	12	0.00075	0.5496	0.8809ns
Season × agroecological zone × flowering week	12	0.00163	1.1916	0.2882ns
Season × agroecological zone × species × flowering week	24	0.00220	0.8022	0.7338ns

* Indicates significant and **ns** indicates not significant

5.4.2 Discussion

The abundance of many insects changes with time and space (Baldacchino *et al.*, 2014). The underlying causes of such variations differ across insect taxa. Fluctuation of syrphid flies abundance has been reported to be related to both biotic and abiotic factors (Sajjd *et al.,* 2010), and the extent of fluctuations may also differ with time and space. This work therefore, revealed the spatial and temporal abundance of Hoverflies associated with cultivated cucurbit crops across two different agroecological zones of the Morogoro region.

The results have shown that the mountainous zone which is a high altitude area recorded the highest number of hoverflies compared to the plateau zone. The possible reason for this could be the presence of favorable microclimate, high diversity of nearby vegetation and abundant food prevailed throughout the study period. These results are in conformity with few previous studies by Ansari and Memon (2017) and Sengupta *et al.* (2019) which indicated highest number of syrphid flies in high altitude areas exceeded that of hymenoptera and were strongly influenced by both environmental factors and number of flowered plants. Similar conclusion was also reached by Varah *et al.* (2020) who reported that the abundance of insect pollinators is likely to be influenced by presence of floral resources, nesting sites and climatic conditions of a particular area. However, results of this study have shown that season had no direct significant effects on abundance of syrphid species although it could be linked to variation in abundance of floral resources.

The results also indicated that there was significance fluctuation in abundance among *Eumerus* sp1, *E. megacephalus* and *T. floralis* across the two different agroecological zones. This could also be linked to variability in weather conditions, floral resources and intrinsic adaptive characteristics among species to different agroecological zones. The results are consistent with the findings by Sajjid and Saeed (2010) and Moquet *et al.* (2018) who reported that some syrphid species are well adapted to high altitude and some to low area, and their fluctuation were linked to both floral resources and altitude adaptabilities. Similar conclusions were also reached by Pineda and Marcos-Garcia (2008) and Sengupta *et al.* (2019) who found that syrphid species were more active throughout the study period and their population dynamics across altitudes were due to variability of weather conditions and floral resources.

Moreover, the results of this study have showed that flowering period and its interactions had no significance effects on abundance of dominant syrphid species in the study area. These findings were also similar with that by Lazaro *et al.* (2013) who observed no significance effects of flowering period on abundance of hoverflies species and linked the shortage of pollinator visits with climatic conditions and longer flowering durations.

5.5 Conclusion

It is therefore, noteworthy concluding that *Eumerus* sp1, *E. megacephalus* and *T. floralis* were the most abundant species and their abundance fluctuations is linked to differences in agroecological zones and possibly with intrinsic adaptive characteristics among these species. Thus, this study document probably for the very first time, the spatial and temporal abundance of hoverflies associated with cucurbitaceous production systems in Tanzania. This study should therefore serve as a bassline survey and guide to the stakeholders in designing a sustainable pollinator conservation strategies.

References

Aizen, M. A., Garibaldi, L. A., Cunningham, S. A. and Klein, A. M. (2009). How much does agriculture depend on pollinators? Lessons from long-term trends in crop production. *Annals of Botany* 103(9): 1579 – 1588.

Anon (2002). *Morogoro Regional Socio-Economic Profile*. Morogoro Regional Commissioner’s Office, Morogoro. 229pp.

Ansari, A. and Memon, N. (2017). Seasonal variation and diversity of hoverflies fauna (dipter: syrphidae) in central sindh, Pakistan. Sarhad *Journal of Agriculture* 33(4): 653 – 660.

Artins, R. O. P. M., Geral, D. D. B. and Federal, U. (2001). Seasonal Abundance and Species Composition of Flower-Visiting Flies. *Neotropical Entomology* 30(3): 351 – 359.

Baldacchino, F., Porciani, A., Bernard, C. and Jay-Robert, P. (2014). Spatial and temporal distribution of Tabanidae in the pyrenees mountains: The influence of altitude and landscape structure. *Bulletin of Entomological Research* 104(1): 1 – 11.

Bashir, M. A., Saeed, S., Sajjad, A., Khan, K. A., Ghramh, H. A., Shehzad, M. A., Mubarak, H., Mirza, N., Mahpara, S., Rehmani, M. I. A. and Ansari, M. J. (2019). Insect pollinator diversity in four forested ecosystems of southern Punjab, Pakistan. *Saudi Journal of Biological Sciences* 26(7): 1835 – 1842.

Classen, A., Eardley, C. D., Hemp, A., Peters, M. K., Peters, R. S., Ssymank, A. and Steffan-Dewenter, I. (2020). Specialization of plant–pollinator interactions increases with temperature at Mt. Kilimanjaro. *Ecology and Evolution* 11: 2182 – 2195.

Classen, A., Eardley, C. D., Hemp, A., Peters, M. K., Peters, R. S., Ssymank, A. and Steffan-Dewenter, I. (2020). Specialization of plant–pollinator interactions increases with temperature at Mt. Kilimanjaro. *Ecology and Evolution* 11: 2182 – 2195.

Courtney, G. W., Pape, T., Skevington, J. H. and Sinclair, B. J. (2009). *Biodiversity of Diptera.* Blackwell publishing, Canada. 38pp.

De Meyer, M. A. R. C., Goergen, G. and Jordaens, K. (2020). Taxonomic revision of the Afrotropical Phytomia Guérin-Méneville (Diptera: Syrphidae). *Zootaxa* 4803(2): 201-250.

Garibaldi, L. A., Sáez, A., Aizen, M. A., Fijen, T. and Bartomeus, I. (2020). Crop pollination management needs flower-visitor monitoring and target values. *Journal of Applied Ecology* 57(4): 664 – 670.

Habel, J. C. and Ulrich, W. (2020). Ecosystem functions in natural and anthropogenic ecosystems across the East African coastal forest landscape. *Biotropica* 11: 1–10.

Kearns, C. A. (2001). North American Dipteran Pollinators : Assessing their value and conservation status. *Conservation Ecology* 5(1): 1–11.

Kirk-Spriggs, A. H. and Sinclair, B. J. (2017). *Manual of Afrotropical Diptera Volume 2. Nematocerous Diptera and lower Brachycera*. South Africa National Biodiversity Institute, Pretoria, South Africa. 956pp.

Klein, A. M., Vaissière, B. E., Cane, J. H., Steffan-Dewenter, I., Cunningham, S. A., Kremen, C. and Tscharntke, T. (2007). Importance of pollinators in changing landscapes for world crops. Proceedings of the Royal Society: *Biological Sciences* 274(1608): 303 – 313.

Larson, B. M. H., Kevan, P. G. and Inouye, D. W. (2001). Flies and flowers: Taxonomic diversity of anthophiles and pollinators. *Canadian Entomologist* 133(4): 439–465.

Latif, A., Malik, S. A., Saeed, S., Zaka, S. M., Sarwar, Z. M., Ali, M., Azhar, M. F., Javaid, M., Ishtiaq, M., Naeem-Ullah, U., Naoreen, M., Khan, K. A., Ghramh, H. A. and Shahzad, M. A. (2019). Pollination biology of Albizia lebbeck (L.) Benth. (Fabaceae: Mimosoideae) with reference to insect floral visitors. *Saudi Journal of Biological Sciences* 26(7): 1548 – 1552.

Lázaro, A., Jakobsson, A. and Totland, Ø. (2013). How do pollinator visitation rate and seed set relate to species' floral traits and community context? O*ecologia* 173(3): 881–893.

Marshall S. A. and Kirk-Spriggs, A. H. (2017). Natural history of diptera. In: *Manual of Afrotropical Diptera, Introductory Chapters and Keys to Diptera Families*. (Edited by Kirk-Spriggs, A. H. and Sinclair, B. J.), South Africa National Biodiversity Institute, Pretoria, South Africa. pp. 135 – 152.

Moquet, L., Laurent, E., Bacchetta, R., and Jacquemart, A. L. (2018). Conservation of hoverflies (Diptera, Syrphidae) requires complementary resources at the landscape and local scales. *Insect Conservation and Diversity* 11(1): 72 – 87.

Mwatawala, M. W., De Meyer, M., Makundi, R. H., and Maerere, A. P. (2006). Seasonality and host utilization of the invasive fruit fly, Bactrocera invadens (Dipt., Tephritidae) in central Tanzania. *Journal of Applied Entomology* 130(9–10): 530 – 537.

Mziray, H. A., Makundi, R. H., Mwatawala, M., Maerere, A. and De Meyer, M. (2010). Host use of bactrocera latifrons, a new invasive tephritid species in Tanzania. *Journal of Economic Entomology* 103(1): 70 – 76.

Pineda, A. and Marcos-García, M. Á. (2008). Seasonal abundance of aphidophagous hoverflies (Diptera: Syrphidae) and their population levels in and outside Mediterranean sweet pepper greenhouses. *Annals of the Entomological Society of America* 101(2): 384 – 391.

Sajjad, A., Saeed, S. and Ashfaq, M. (2010). Seasonal variation in abundance and composition of Hoverfly (Diptera: Syrphidae) communities in Multan, Pakistan. *Pakistan Journal of Zoology* 42(2): 105 – 115.

Sawe, T., Nielsen, A., Totland, Ø., Macrice, S. and Eldegard, K. (2020). Inadequate pollination services limit watermelon yields in northern Tanzania. *Basic and Applied Ecology* 44: 35 – 45.

Sengupta, J., Naskar, A., Maity, A., Hazra, S., Mukhopadhyay, E., Banerjee, D. and Ghosh, S. (2016). An Updated Distributional Account of Indian Hover flies (Insecta: Diptera: Syrphidae). *Journal of Entomology and Zoology Studies* 4(6): 381–396.

Ssymank, A., Kearns, C. A., Pape, T. and Thompson, F. C. (2008). Pollinating flies (Diptera): a major contribution to plant diversity and agricultural production. *Biodiversity* 9(2): 86 – 89.

Totland, O. (1994). Influence of climate, time of day and season, and flower density on insect flower visitation in alpine Norway. *Arctic and Alpine Research* 26(1): 66 – 71.

Tschorsnig, H. and Herting, B. (2001). *The Tachinids (Diptera : Tachinidae) of Central Europe : Identification Keys for the Species and Data on Distribution and Ecology*. State Museum of Natural Science, Stuttgart. 150pp.

United Republic of Tanzania (2002) *Morogoro Regional Socio-Economic Profile*. Morogoro Regional Commissioner's Office, Morogoro. 229pp.

Varah, A., Jones, H., Smith, J. and Potts, S. G. (2020). Temperate agroforestry systems provide greater pollination service than monoculture. *Forest* 10(981): 1 – 20.

Whitworth, T. (2014). Keys to the genera and species of blow flies (Diptera: Calliphoridae) of the West Indies and description of a new species of Lucilia Robineau-Desvoidy. *Zootaxa* 2663: 1 – 35.

Willcox, B. K., Howlett, B. G., Robson, A. J., Cutting, B., Evans, L., Jesson, L., Kirkland, L., Jean-Meyzonnier, M., Potdevin, V., Saunders, M. E. and Rader, R. (2019). Evaluating the taxa that provide shared pollination services across multiple crops and regions. *Scientific Reports* 9(1): 1 – 10

CHAPTER SIX

6.0 General Conclusions and Recommendations

6.1 Conclusions

This study documents probably for the first time the community structure of pollinating flies associated with cucurbitaceous production systems in the Morogoro region. The two zones are predominated by few abundant species (*Musca domestica*, *Stomaxys calcitrans* and *Sarcophaga* sp1) and many less abundant species (*Eristalinus megacephalus*, *Mesembrius caffer, Eumerus* sp1 *and Toxomerus floralis*). Highest number of pollinating flies/trap/week was recorded at the mountainous zone which was also found to be the most species rich zone compared to the plateau zone. Thus, both indexes of diversity placed mountainous zone as the most abundant and species rich zone. Different in agroecological zones, and flowering week showed significance effects in abundance and visitation rates among the dominant species of Syrphidae between the two seasons. In both zones, the pollinating flies' communities were hierarchical structured and were initially colonized by few abundant species particularly *Musca domestica*, *Stomaxys calcitrans* and *Sarcophaga* sp1 before many rare species were established in the communities. Muscidae (58.74%), Calliphoridae (12.49%) and Sarcophagidae (20.24%) were the most abundant and predominant families while Syrphidae (4.94%), Tachinidae (2.36%), Agromyzidae (0.73%) and Simuliidae (0.47%) were the least abundant families in the study area. Among the 22 species of pollinating flies identified as visitors of cucurbit flowers *Eristalinus megacephalus, Mesembrius caffer, Eumerus* sp1 *and Toxomerus floralis* were recognized to most consisted flower visitors and therefore were considered as species of great importance and benefit for cucurbit production in the study area

6.2 Recommendations

Since the results seem to suggest that Syrphidae family was represented by many species of agricultural importance compared to other families, therefore this study recommends more studies should be conducted to explore their pollination efficiency, distribution as well as their present status in both agroecological and conventional farming systems. Such study will not only provide sufficient information to stakeholders regarding the diversity and abundance of syrphid flies but also will explore the potential roles of syrphid flies as pollinators in different agroecosystems. The results from this study can be used to assist stakeholders in designing sustainable pollinator conservation management programs for increased agriculture production.

APPENDICES

	Plateau zone				Mountaino	
	Wet season		Dry season		Wet season	
Pollinators	Abundance	RA (%)	Abundance	RA (%)	Abundance	I

Eristalinus megacephalus	19	27.1	22	26.5	27	3
Paragus borbonicus	5	7.1	3	3.6	4	4
Allograpta sp1	1	1.4	2	2.4	0	0
Eumerus sp1	2	2.9	2	2.4	2	2
Mesembrius caffer	21	30.1	31	44.3	28	3
Phytomia curta	5	7.1	4	4.8	10	1
Toxomerus floralis	15	21.4	17	24.3	14	1
Syritta fasciata	2	2.9	2	2.4	1	1
Sub total	70	100	83	100	86	1
Sub total		153(46.1%)				1
Grand total				332(100%)		

Appendix 1: Syrphid flies abundances counted during observation of cucurbit flower visitors in the plateau and mountainous zones during March to July 2020.

Note: RA=Relative Abundance